

APRIL 1984

VOL. 6 NO. 4

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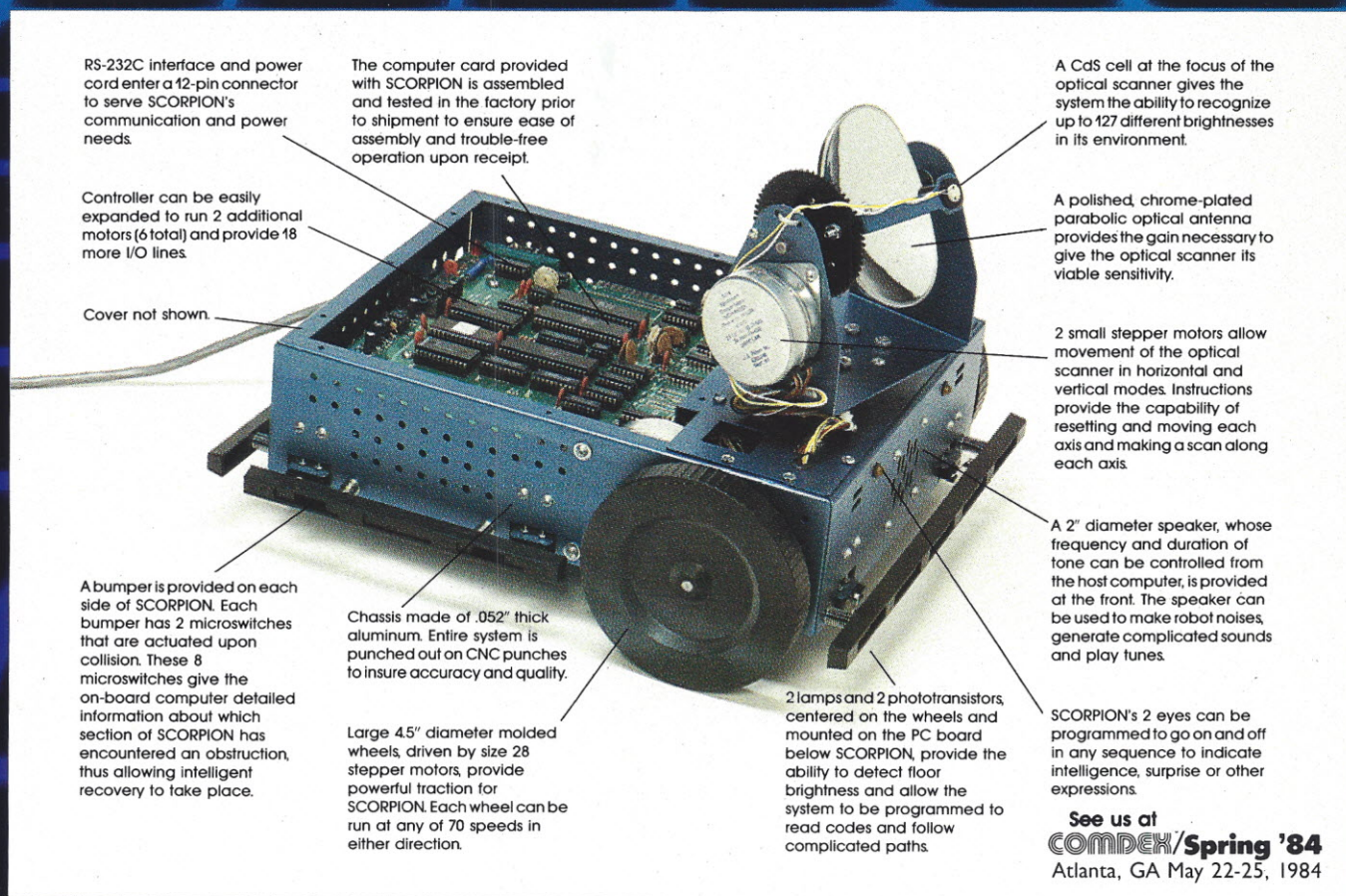
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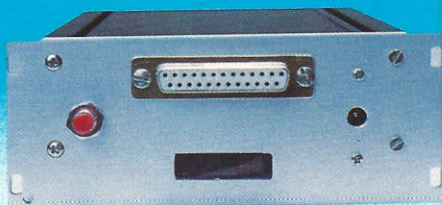
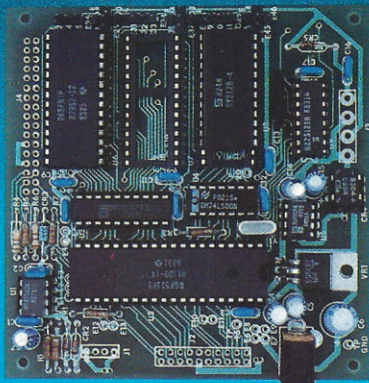
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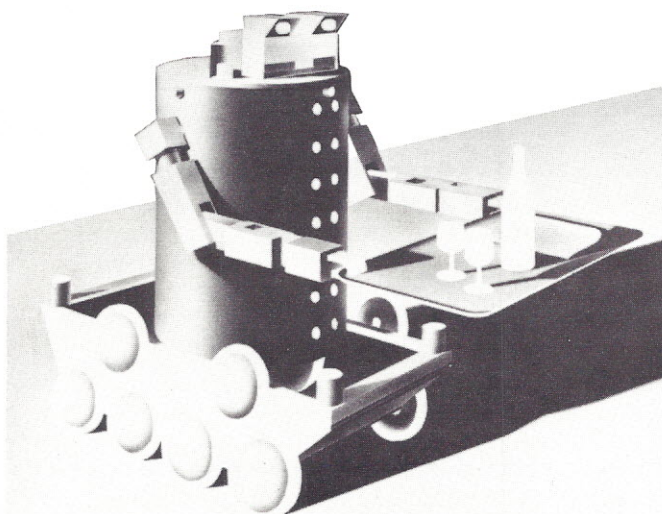
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ROBOTICS AGE™

APRIL 1984

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GUEST EDITORIAL

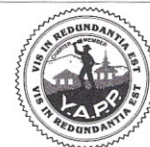
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Sometimes, the simplest of sensors can produce a dramatic result. Modelled from the cats' whiskers of nature, these experimental touch sensors close the loop for a robot arm.
- 21 Bipedal Balance by Thomas A. Easton
An understanding of how living bipeds maintain their balance provides design ideas for constructing bipedal machines.
- 27 Patent Probe: Robot Warehouse by Russ Adams
Jeeve, go get box number 33 and send it to assembly station 10! The ultimate in materials handling is the robot warehouse. See one approach described in Patent #4,395,181.
- 29 Armega 33 Part II: The Electrical Components by D. F. Boyd
A look at Armega 33's electrical and electronic control components.

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About the cover: Shiva, the cat, in R. Andrew Russell's article was the inspiration for this month's cover by Robert Tinney. Robert has caught the essence of how we can mirror nature's methods with our applied technology.

BPA Membership (SMA Division) Applied for, August 1983



International Personal Robot Congress

ALBUQUERQUE, NEW MEXICO April 13-15, 1984

ABOUT THE CONGRESS...

IPRC '84 will offer an opportunity for robot enthusiasts to display their creations and enter them in various *competitions*. There will also be *commercial exhibits* and *seminars* on personal robots, as well as *cultural events* portraying the history and mythology of personal robots.

The Congress will open with a major ceremony—an event complete with dignitaries, limelight, media, robots and fanfare. The Congress will close with an Awards Brunch recognizing the individual achievements of the Personal Robot Developers in their exhibitions and competitions.

PROGRAM

- SOFTWARE DESIGN CONSIDERATIONS
- HARDWARE DESIGN CONSIDERATIONS
- ROBOTS IN EDUCATION
- HUMAN SERVICES
- LEGAL ISSUES
- BUSINESS OPPORTUNITIES
- FUTURE OF PERSONAL ROBOTS

PERSONAL ROBOT DEVELOPERS: COMPETITIONS

The Personal Robot Developers (individuals, clubs, classes... whoever has a robot worth seeing) will exhibit their creations for a modest fee at the Robot Shops. Their operators can maintain, repair and modify their systems in these shops in view and within speaking distance of interested exhibit attendees. The PRDs will engage in a series of competitions. Awards will be given in the areas of "most useful," "most entertaining" and "open." The categories of competition will be junior/senior high school, college, and general. Competition will culminate with the "Golden Droid" awards to be presented at the Sunday Brunch.

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- commercial exhibits
- Robot Shops and competitions
- featured speeches
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Editorial

GUEST EDITORIAL

A Robot Is a Robot Is a Robot

BY JOSEPH ENGELBERGER

In the beginning there were industrial robots designed to displace people in subhuman factory jobs. Twenty-five years after conception, the industrial robot has a foothold in every industrialized society worldwide.

Meanwhile, in an unrelated phenomenon, electronic arcade games became a frenzied fad, to be followed by mass-produced living room versions, that in turn spawned the home computer.

Providing binding energy were the highly entertaining science fiction movies that celebrated superior robotic beings like R2D2 and C3PO. Even the sales promotion robots that roll around under hidden human control helped.

Now, what can one really do with a home computer after one has balanced his checkbook and played Pac-Man with the kids? Not much, but suppose we add a peripheral that can provide a new kind of fun? Enter the personal robot!

This year hosts the 13th International Symposium on Industrial Robots and the 1st Congress on Personal Robots. The former is a sophisticated full-blown event while the latter is bubbling over with naive awkward fervor. Industrial robots and personal robots are poles apart today. Giant corporations flex their muscles in the industrial arena while hobbyists are developing an underground culture in personal robotics. Yet, this schism cannot continue.

Industrial robots are gaining sensory perception, advanced language and mobility. And so are the hobby robots. With so many bright enthusiasts in the game the two robotics cultures must converge. Before this decade is out it should become evident that robots no longer need the distinctions *industrial* and *personal*. They will all be just robots "under the skin."



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Calendar

APRIL

Call for papers. The Workshop on Non-monotonic Reasoning is sponsored by the American Association for Artificial Intelligence. The workshop aims to assemble theoreticians and practitioners from across the AI field who recognize a need for nonmonotonic reasoning. The objective is to identify those forms of plausible reasoning which arise in different areas of AI, to isolate common patterns, to entertain various accounts of these reasoning patterns, and to evaluate their suitability and limitations. For more information regarding manuscript submission, due by 1 April, contact: Ray Reiter, General Chairman, Department of Computer Science, University of British Columbia, Vancouver, BC V6T 1W5, CANADA.

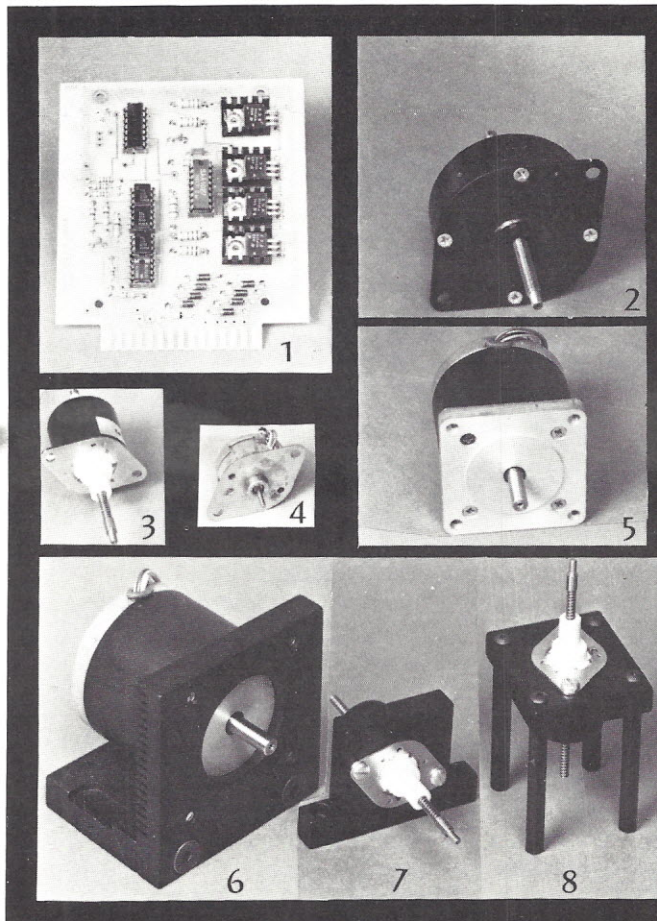
Call for papers. The National Conference on Artificial Intelligence, AAAI-84, is the fourth national conference sponsored by the American Association for Artificial Intelligence. It will be held in Austin, TX on 6-10 August 1984. The purpose is to promote scientific research of the highest caliber in AI by bringing together

researchers in the field and by providing a published record of the conference. Authors are invited to submit papers on: AI and Education, AI Architectures and Languages, Automated Reasoning, Cognitive Modeling, Expert Systems, Knowledge Representation, Learning, Methodology, Natural Language, Perception, Philosophical and Scientific Foundations, and Robotics. For more information regarding manuscript submission, due by 2 April, contact: American Association for Artificial Intelligence, 445 Burgess Drive, Menlo Park, CA 94025, telephone (415) 328-3123.

April. Robot Olympics. California State College, San Bernardino, CA. Contact: Robot Olympics Committee, Computer Center, California State College, 5500 State College Parkway, San Bernardino, CA 92407. The first Robot Olympics will be held on a weekend in April. Sponsored by various robot manufacturers, software developers, publishers, and dealers, the weekend will also sponsor introductory and application workshops. Competitions are designed for school grades kindergarten through 12.

5-6 April. Computers and Young Children. University of Delaware, Newark, Delaware. Contact: Computers and Young Children Conference, Division of Continuing Education, University of Delaware, Newark, DE 19716. The program is designed for teachers, administrators, and researchers in preschool and early childhood education. Hands-on workshops and speakers from the Children's Television Workshop and Apple Education Foundation are featured. An open-to-the-public Computer Show follows the conference.

13-15 April. International Personal Robot Congress & Exposition 1984. Albuquerque, NM. Contact: International Personal Robot Congress, 1547 S. Owens St., #46, Lakewood, Colorado 80226, telephone (303) 278-0662. The Congress offers displays, exhibits, seminars, a number of cultural events portraying the history and mythology of personal robots, and an opportunity for robot enthusiasts to display their creations and enter them in various robot competitions. A steering committee has been formed with representatives from Heath, RB Robot, and Androbot. Nels Winkless, robotics writer,



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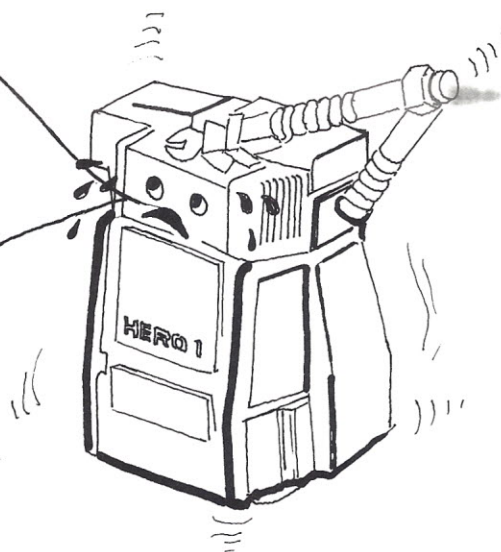
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SPRING 1980: Microcomputer Based Path Control; Robotics Research in France; Multiple Sensors for a Low-Cost Robot; the Robots of Autofact II; Inside Big Trak.

SUMMER 1980: Industrial Robots; Today and Tomorrow; Introducing the Minimover 5; Advances in Switched Mode Power, Part II.

FALL 1980: Using Optical Shaft Encoders; Interview with Victor Scheinman; Robot Vision for Industry; The AutoVision System; Industrial Robotics '80; Robots on Your Own Time; Superkim Meets ET-2.

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SEP/OCT 1981: Bullish Days in the Robot Business; Edge Detection in Man & Machine; Continuous Path Control with Stepping Motors; Build a Low-Cost Image Digitizer, Report from JACC-81; The Robot Builder's Bookshelf.

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JULY/AUG 1982: The Microbot Teach-mover; Some Notes On the Rhino XR-1 and Minimover 5; Patent Probe; Use Your Apple As a Robotics Development System; IBM Robots; Adapting a Speech Synthesizer; Constructing an Intelligent Mobile Platform, Part I.

SEP/OCT 1982: Roving Robots; Report on SIGGRAPH '82; Patent Probe No. 4,221,997; Constructing an Intelligent Mobile Platform, Part II; The Physics of One-Legged Mobile Robots.

NOV/DEC 1982: Robot Wrist Actuators; Patent Probe; A Microcomputer Based, Real-Time Robot System; The Physics of One-Legged Mobile Robots; Part II; 1982 AAAI Conference; Armatron: A Study in Arm Engineering; Invention Documentation: A Primer.

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JULY/AUG 1983: The Get Away Special, Part I; A Nose for the Heath Hero-1; Patent Probe: Am-

bulatory Platform; Robotics and the Law: Organizing the Venture; A Table of Contemporary Manipulator Devices.

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FEBRUARY 1984: GRASP: From Computer Aided Robot Design to Off-Line Programming; Design and Construction of a Five-Fingered Robotic Hand; Patent Probe: Omnidirectional Vehicle; Using Microprocessors with Radio-Control Servos; Designing a Reliable Voice-Input Robot Control Language; Part II, The Scorpion: Motor Control Instructions.

MARCH 1984: Part I, Armege 33: Mechanical Design; Patent Probe: Robot Computer Chess; Part III, The Scorpion: Commands with Responses; A Simple Computer Interface.

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Calendar

and Russ Eberhart, robot retailer, are also on the committee.

Conference events include robot competitions, instructional sessions, and speakers such as Joseph F. Engleberger, David L. Heiserman, Nolan Bushnell, and Isaac Asimov. The various instructional sessions include hardware and software design considerations; legal issues; human services; robots in education; business opportunities; and the future of personal robots.

23-26 April. Robotics and Remote Handling in Hostile Environments. Sheraton Hotel, Gatlinburg, TN. Contact: Norbert R. Grant at (615) 574-7123 or Howard W. Harvey at (615) 483-0228, or write to Technical Program Chairman, PO Box 326, Oak Ridge, TN 37830. The meeting is sponsored by the American Nuclear Society's Remote Systems Technology Division (ANS/RSTD) and the Oak Ridge/Knoxville ANS Section. Session titles are: *History of Manipulators and Robotics*; *Sensory Systems*; *Control Technology*; *Manipulator and Robot Applications*; *Remote Systems Applications in the Nuclear Industry—Fission*; *Remote System Applications in Other Hostile Environments*;

Technology Development and Remote Systems Technology Developments at ORNL.

24-26 April. Robotics Conference. Huntsville, Alabama. Contact: Sue Charles, Conference Coordinator, Division of Continuing Education, University of Alabama in Huntsville, Huntsville, AL 35899, telephone (205) 895-6015. This three-day conference includes a one-day tutorial on robotics and its applications, with hands-on training, and two days of presentations on industrial robots in manufacturing, welding, and hazardous environments as well as new trends in vision, sensing, expert systems, and future concepts.

24-25 April. 1984 Conference on Intelligent Systems and Machines. Oakland University, Rochester, MI. Contact: Professor Nan K. Loh or Donald R. Falkenburg, Center for Robotics and Advanced Automation, School of Engineering and Computer Science, Oakland University, Rochester, MI 48063. The conference will be hosted by the Center for Robotics and Advanced Automation in cooperation with sponsoring government agencies and private in-

dustry. The conference's aim is to foster communication among engineers, scientists, government officials, and military services regarding issues, trends, and needs in research and development. Areas covered include artificial intelligence, hardware systems, software systems, and applications.

MAY

7-11 May. 1984 Computer-Aided Engineering and Manufacturing Seminars and Exhibition. North Carolina State University, McKimmon Center, Raleigh, NC 27605. Contact: Alice Strickland, NCSU, Division of Continuing Education, Box 5125, Raleigh, NC 27650, telephone (919) 737-2261.

7-11 May. Microcomputers in Control Systems Including Interfacing Methods. Course #5220C. Ottawa, Canada. Contact: George Harrison, The George Washington University, Division of Continuing Education, Washington, DC 20052, telephone (800) 424-9773 or (202) 676-6106. This course is designed to familiarize

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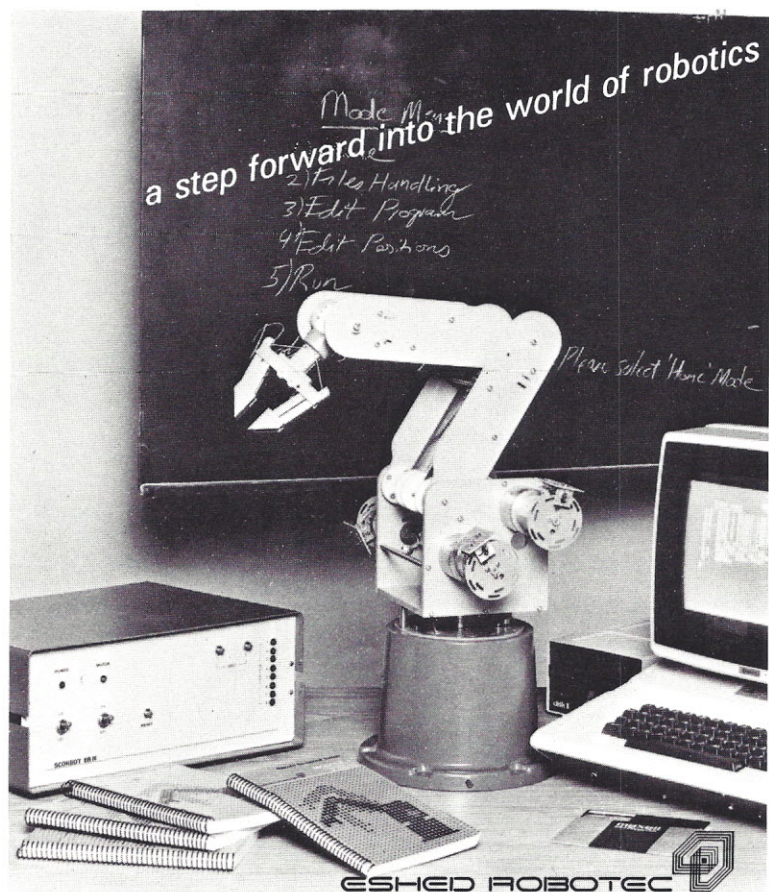
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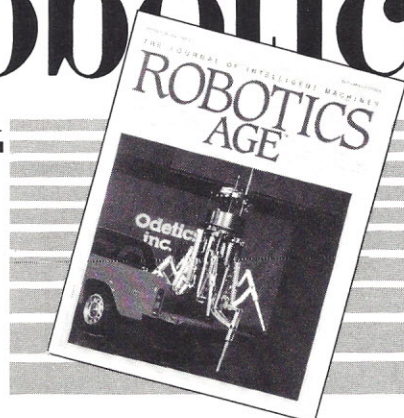
We've read about robots for decades in the science fiction genre. Today's creative engineers are fast making yesterday's fiction obsolete. The technology is becoming real... Real engineering of real-time computer systems for real applications—that's what robotics is all about. **Robotics Age** is your monthly window on the nuts, bolts, bits and design concepts of this new microprocessor hardware and software technology. The inspiration of science fiction plus the practical information in **Robotics Age** keep you abreast of this exciting field.

Intelligent machines are already a major part of our world. We see the new realities of walking machines, autonomous space and undersea explorers, factory automation, feedback from vision and touch, robots of the industrial and personal flavor. We see sentry robots patrolling homes, forts, factories and offices. We see the prospect of the automotive autopilot and personal robotics.

Robotics Age looks to this future with articles about design concepts, products and practical experimental techniques. You'll find advertising from the suppliers of components and systems for intelligent machine engineering, as well as in-depth tutorials and reviews of available technologies. You'll find numerous practical and proven design techniques. You'll learn how to use microcomputer electronics where it counts, how to build simple, reliable touch sensors, how to use visual and aural pattern recognition to gain information about the real world, how to design programs that plan strategies of operation. You'll find articles on what makes today's personal robotics experiments tick, and more....

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In past issues, we've had several articles on walking robots—the design problems of legged mobility. One article described aspects of a one-legged hopping robot. Another described ODEX I, a recently designed experimental six-legged mobile robot. ODEX I has been widely publicized, including an appearance on a syndicated television series as well as



superficial articles in numerous general magazines. If you were a subscriber in 1983, you read about ODEX I first. In addition to being first, our article on ODEX I contained a level of detail only available in the **Robotics Age** style of technical article... and nowhere else. So, don't miss out on the opportunity to find out about the latest developments in detail and ahead of the crowd—subscribe today.

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Calendar

participants with the capabilities of microcomputers to replace digital, analog, and electromechanical control elements in control applications. Participants are shown the current state of technology in microcomputers and become familiar with both the economic and technical aspects of the use of such systems as replacements for more conventional control methods. This course is for technicians, engineers, and technical managers who are interested in the applicability, selection, and use of microcomputers, and who want hands-on understanding of applications and interfacing of microcomputers in control systems.

22-24 May. Control Expo 84. O'Hare Exposition Center, Rosemont, Illinois. Contact: Tower Conference Management Company, 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100. Control Expo is sponsored by *Control Engineering Magazine*. Over 6,000 controls specialists are expected to attend this year's exposition. A comprehensive conference program of 25 technical sessions cover topics ranging from controlling flexible assembly systems, sensors for adaptive control systems, applications

and advances of standalone digital process controllers, fitting robots to the applications, and advances in the control of large batch processes.

JUNE

4-7 June. Robots 8. Cobo Hall, Detroit, MI. Contact: Jeff Burnstein, Robotics Institute of America, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-0778. The theme for this year's annual Robots show is "Merging Technologies." More than 20,000 specialists, industrialists, and manufacturing engineers, and executives are expected to attend the four-day event. The conference features more than 80 leading experts explaining new aspects of robot implementation, applications, and research. The exposition will occupy the entire main level and additional exhibit space at Cobo Hall.

19-21 June. 3rd Canadian CAD/CAM & Robotics Exposition and Conference. Toronto International Centre of Commerce. Contact: Hugh F. Macgregor & Associates, 662 Queen Street West, Toronto, Ontario M6J 1E5

CANADA, telephone (416) 363-2201. This exposition is the major Canadian marketplace for advanced manufacturing systems. Conference topics include: Robotics Justification for Management, CAD/CAM, Robotics Education, Robotics Socio-Economic Considerations, Robotics Engineering, and Robotics Applications.

JULY

9-12 July. 1984 National Computer Conference. Las Vegas Convention Center, Las Vegas, NV. Contact: Ann-Marie Bartels, Las Vegas Convention Center, Las Vegas, NV, telephone (703) 558-3613. *Enhancing Creativity* is the theme of the twelfth annual NCC. The conference will focus on how the widespread availability of computing resources is altering the office, factory, and home.

23-27 July. SIGGRAPH '84. Minneapolis, MN. Contact: SIGGRAPH Conference Office, 111 East Wacker Drive, Chicago, IL 60601, telephone (312) 644-6610.

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Calendar

This year's SIGGRAPH Conference attendees will be treated to a vast array of technical and exhibit offerings. The program includes up to 30 one or two-day courses, panels on topical computer graphics issues, a larger number of exhibits, a design arts show, and the premier of the first totally computer-generated Omnimax film.

AUGUST

1-3 August. The Computer: Extension of the Human Mind. Eugene, Oregon. Contact: Summer Conference Office, College of Education, University of Oregon, Eugene, Oregon 97403. This conference, the third annual computer and instructional technologies conference to be sponsored by the Center for Advanced Technology in Education, will focus on the needs of the individual who has become responsible for school and district-level use of computers and other emerging instructional technologies. Both general and special interest group sessions

will be supplemented with an extensive vendor hall and film/video theater related to computer technology in education. Pre- and post-conference workshops will be conducted on the educational uses of computers.

5-8 August. Lisp and Functional Programming. University of Texas at Austin. Contact: Robert S. Boyer, University of Texas at Austin, Institute for Computing Science, 2100 Main Building, Austin, TX 78712, telephone (512) 471-1901. This is the third in a series of biennial conferences on the Lisp language and issues related to applicative languages. Areas of interest include implementation problems; programming environments; large implementations; support tools; architectures; microcode and hardware implementations; significant language extensions; lazy evaluation; functional programming; logic programming; combinators; FP; APL; Prolog; and other languages.

20-24 August. National Conference and Exhibition on Robotics—1984. Melbourne,

Australia. Contact: The Conference Manager, Institution of Engineers-Australia, 11 National Circuit, BARTON, A.C.T. 2600, AUSTRALIA, telephone (062) 73-633. The conference promises to be the most important Australian robotic event held to date. It will have a strong application and education emphasis. Leading Australian robot users, developers, and researchers will present their experience and views on this important high technology area.

NOVEMBER

27-29 November. Robots-West. Anaheim Convention Center, Anaheim, CA. Contact: Jeff Burnstein, Robot Institute of America, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-0778. Robots-West is RIA's first regional show. It will feature exhibits by leading robot manufacturers and component suppliers. Approximately 6,000 visitors are expected to attend the three-day exposition and conference.

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Letters

Startup Aid

Thank you for including the RMP 2000 in the Sept/Oct 1983 New Products column. Your magazine provides a valuable service by devoting several pages each issue to new robot-related products. This service is valuable not only to *Robotics Age* readers, but also to established companies and start-ups such as Bingel Robotics.

Thank you again,
Tom Bingel, President
Bingel Robotics Company
3540-244 SW Archer Rd.
Gainesville, FL 32608

GAS Handbook

Could you please provide the address necessary to obtain the GAS User's Handbook and related information?

Thanks
Mr. S. Pacitti
120 Homewood Ave.
North York, Ontario M2M 1K3
CANADA

The Get Away Special (GAS) Handbook describing how to design experiments for transportation on special Space Shuttle launches can be obtained from: The Get Away Special Program, Technical Liaison Office/Code 741, Goddard Space Flight Center, Greenbelt, MD 20770.

DCAM Sources

We appreciate your covering the Micro DCam in your last issue of *Robotics Age*, but we would like to clarify some of the wording in the interest of our suppliers.

Micromint manufactures the camera circuitry and interface electronics of the Micro DCam, but the 256 by 128 silicon image sensor itself is manufactured by Micron Technology in Boise, Idaho. The editing of our new products announcement makes it seem we are the image sensor manufacturer.

We would not bother to bring this to your attention except that your magazine does such a great job it produced a flood of inquiries concerning the Micro DCam. We're not complaining!

Sincerely,
Joyce Chandler
Micromint, Inc.
223 Mellow Rd
Tolland, CT 06084

Armatron Recognized

You had an article on Radio Shack's Armatron in your Nov/Dec 1982 issue [*also the January 1984 issue, ed.*]. Would this robot arm be a good one to buy? Were there any tests conducted between this robot and any other robot arms?

Very truly yours,
Bruce Cook
127 Oak Glen Dr.
San Antonio, TX 78209

Although the Radio Shack Armatron is an intriguing mechanical device, it is not a true robot. Our coverage of the machine has stressed the Armatron's educational value. If you wish to discover the intricacies of mechanical gearing, controls, and linkages, the Armatron is definitely a good value. At \$35, how can you go wrong? However, don't expect to connect the Armatron to your computer as soon as you get it home. Computer control requires major modifications.

E.T. Roll Home

I wish to comment about a recent Patent Probe which appeared in the February, 1984 issue and described Hua T. La's "Omnidirectional Vehicle." I am particularly interested in figure 1, "a front elevational view of a wheel defined by the La patent . . . 4,237,990 Hua T. La; December 1980 . . ."

It appears that several legal precedents might have been established by the issuance of this patent.

I'm familiar with at least three written accounts of this wheel configuration beginning with that given by a man named Ezekiel around 593 BC. Ezekiel was studying to become a priest as had his father Buzi before him. About 597 BC he was deported to Babylon with other Jews by King Nebuchadnezzar after the surrender of Jerusalem to the Babylonian Armies by King Jehoiachin. Soon after his 30th birthday he was called into service as a prophet. He kept meticulously de-

New

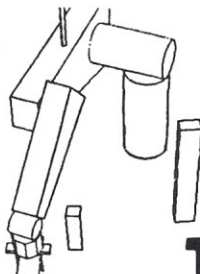
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Letters

tailed and orderly records of the things that he saw.

The Book of Ezekiel is full of "visions" of wheeled vehicles. Chapter 1, verses 16 and 17 make the first actual mention of wheels;

"The appearance of the wheel and their work was like unto the color of beryl: and the four had one likeness: and their work was as it were a wheel in the middle of a wheel...."

"When they went they went up on their four sides: and they turned not when they went...."

"...and when the living creatures went the wheels went by them...."

Unfortunately, the language of the day was such that it could not identify the craft, leaving us of Ezekiel's future with descriptions of "animals" that moved about upon wheels.

He continues recording his impressions of the things that he witnesses and then again in

chapter 10 verse 11 he makes mention of the wheels:

"As I was looking at the four animals I saw four wheels touching the ground ... all four wheels were alike ... each had another wheel intersecting it at right angles...."

Most notable, however, are his descriptions of how they operated:

"When the animals moved they could go in any direction without turning. They all moved in the direction they wanted to go without having to turn round...."

This is most clearly a functional description of the omnidirectional wheel patented by Mr. La. Without a doubt, Ezekiel saw vehicles that came from the air, landed, and then moved about upon wheels capable of omnidirectional movement without the need to rotate the entire craft. Unfortunately, this information lay unnoticed for centuries.

Then, for whatever reasons, the late 1970's witnessed an upsurge in public interest and speculation in space flight. During this time many people did research into the possibility that Planet Earth had been visited by extraterrestrials and that they'd left a wealth of knowledge, right under our undiscerning noses. These researchers published their findings for all to read and wonder about. One of the most prolific of the researcher/writers was one Erich von Daniken, author of *Chariots of the Gods*.

Mr. von Daniken made mention of many of these curious descriptions written in the Ezekiel texts because he felt that they could be descriptions of spacecraft. Few, however, regarded his work as being of real scientific value.

Independent work by Josef F. Blumrich, author of *The Spaceships of Ezekiel*, later supported much of Mr. von Daniken's research. Mr. Blumrich's book provides an appendix complete with formulae for spacecraft and fuel, all of which were derived from descriptions left behind by Ezekiel.

My questions, however, are centered around the similarity between the wheel illustrated on page 38 of Mr. Blumrich's text and that used to describe Mr. La's patent application on page 21 of the February 1984 issue of *Robotics Age*.

Assuming that these UFOs did (do) exist, isn't it reasonable to believe that the occasional sightings are actually return visits being made to reapply for patent law protection?

Can an invention whose patent rights were established by extraterrestrials be patented by a Terrestrial?

If not, and the existence of UFOs is ever acknowledged and occupants of said UFOs decide to sue for infringement of patent rights—in whose favor might the courts rule?

How did a patent attorney ascertain the presence or lack of "novelty" as defined in 35 US Code 101 when dealing with devices which may or may not have been first introduced by an extraterrestrial?

I enjoy your magazine tremendously and am hoping that through your publication and its efforts to educate the public, America's work in the area of robotics will not lag behind that of the Japanese or the ETs.

Gregory W. Jones, Jr.
Lake Hiawatha, NJ

We have published this letter in the public interest, to provide new legal insights into the potential problems of intergalactic patent applications. Although no staff member has yet completed galactic legal training, I am sure Mr. Jones' questions will be brought up at the next pangalactic jamboree [rgac].

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Closing the Sensor-Computer-Robot Control Loop

R. Andrew Russell, Ph.D.
Department of Electrical and Computer Engineering
The University of Wollongong
PO Box 1144
Wollongong, N.S.W. 2500 AUSTRALIA

I was looking for a simple demonstration of robot control for our department's open day. To hand, I had a newly acquired Mitsubishi Movemaster robot and a Cromemco microcomputer. The Movemaster is a solidly built, five degrees of freedom experimental robot arm. Its step motor drives are controlled by an inbuilt Z-80 microprocessor. "What demonstration could I put together," I asked myself, "which would illustrate the advantages of using sensory feedback to guide a robot?" My demonstration had to conform to the usual constraints of costing very little and not involving too many man-hours of work.

I reasoned that part acquisition is a useful task, so why not show the robot locating and stacking randomly placed objects? I wrote a check list of additional items this demonstration would require:

- A sensor for finding the objects.
- Some method of sending the robot manipulator to a specified point in the search area (a way of converting a specified point in Cartesian xyz coordinates into robot joint coordinates).

- A strategy for finding and accurately locating the objects.

This article describes my implementation of each of these items which have been combined to make a very successful robotics demonstration. The methods I

nature. Many insects and nocturnal animals use antennae and whiskers to check for obstacles and gauge clearances in tight situations. (Shiva the cat shows her whisker sensors in photo 1.)

My whisker sensors consist of a length of metal guitar string, 0.007 in. diameter, which passes through a hole in a piece of copper sheet. The smaller the hole, the more sensitive the sensor. There is a lower limit to the size of hole set by the difficulty of positioning the wire centrally in the hole and by vibration causing spurious responses. When the wire whisker is deflected by contact, the wire touches the side of the hole. This completes a circuit and changes the logic level on a computer input line.

The first sensor I built consisted of an array of

16 whiskers having different lengths and heights. This sensor, shown in figure 1a, was intended to give some two-dimensional information about the height and outline of objects that it touched. To reduce the number of computer interface lines required by this sensor, I designed the scanning circuit shown in figure 2. This circuit



Photo 1. Shiva showing her whisker sensors.

have used should be useful in many other applications.

The Sensor. Vision is the natural first choice of a sensor for locating randomly positioned objects. However, this solution was ruled out on grounds of cost.

Whisker sensors are quite common in

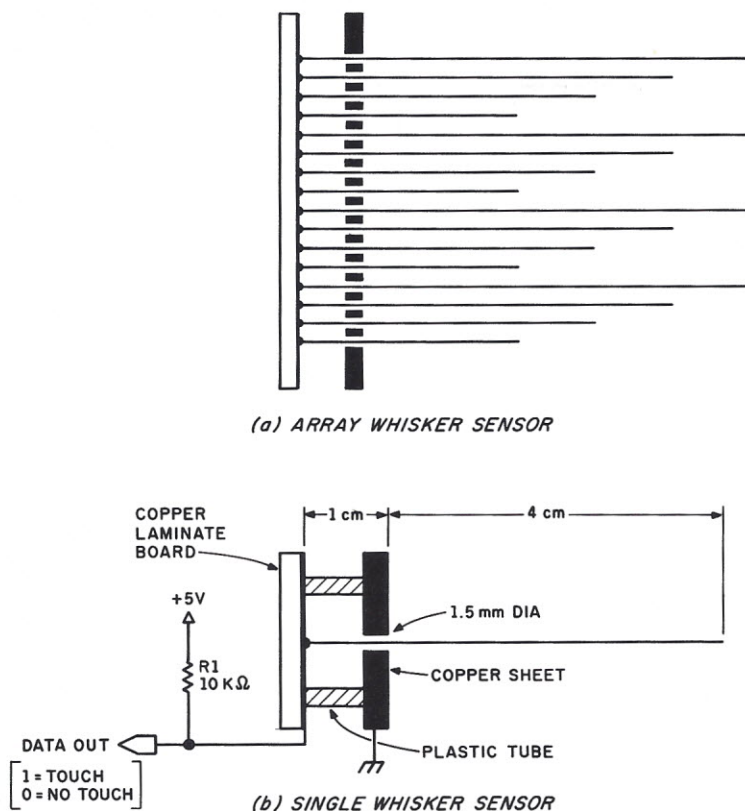


Figure 1. The original whisker sensor, shown in figure 1a, was constructed from 16 guitar wires passed through a copper sheet. Once this was completed, I discovered that the sensor was too large to be placed on the robot hand. The second version, figure 1b, used a single wire for sensing the presence of an object.

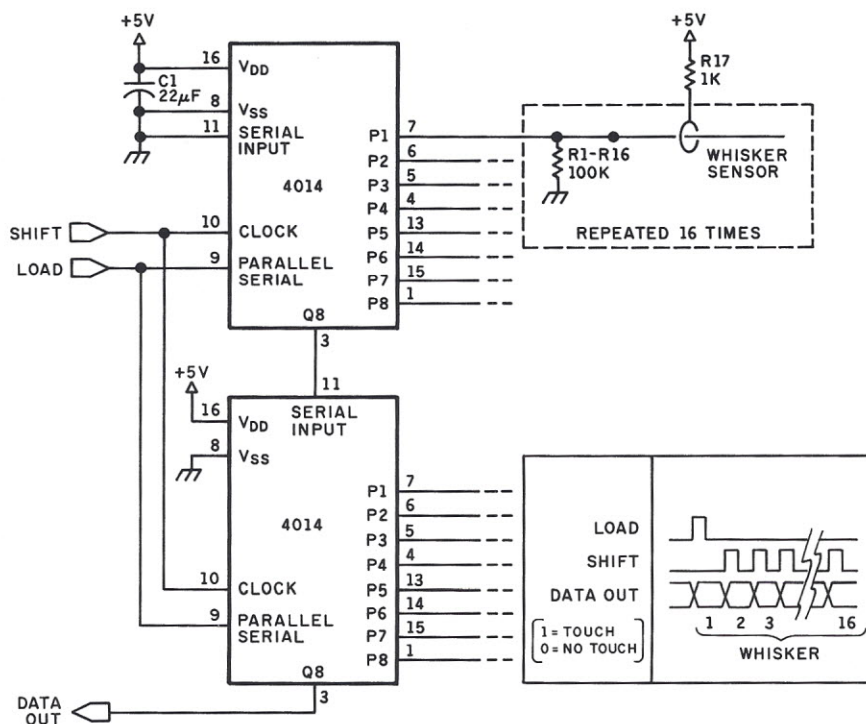


Figure 2. The 16-whisker array sensor interface. This circuit requires only two output lines and one input line to read 16 whisker sensors.

requires two output lines and one input line to read 16 whisker sensors. When the LOAD line is pulsed, the 4014 shift registers are parallel loaded with the present state of each whisker. Successive pulses on the SHIFT line clock data out of the shift registers so that it can be read into the computer from the DATA OUT line. This sensor performed quite well at detecting the outlines of differently shaped blocks. Some results are shown in photos 2, 3, and 4. However, when I came to mount this sensor on the robot gripper, I found that it was too large. A redesign was called for and the result was a much more compact single whisker sensor.

Details of this sensor are shown in figure 1b. This simplified design can only detect the presence of an object, not its shape or orientation. For this reason, I chose to search for cylindrical objects so that when they are standing on end, they can be grasped without worrying about their angle of rotation. If the objects had been square blocks, their angle of rotation would be required so that the manipulator could be oriented to grasp across parallel faces of the block.

Joint Angle Calculation. In the following description, when I write "joint angle" I am referring to the number of step motor pulses to move the robot arm from its nest position to a particular joint angle.

In order to program the locate and grasp operations I needed some way of sending the robot arm to particular points in the search area. If these points are known in advance, I could program the computer with robot joint angles for each point. Unfortunately, some of the points are not known in advance. The usual method used to convert from search area coordinates to robot joint angles is to use matrix transformations. This method is complicated and requires trigonometric functions. Although the programs for this demonstration were originally written in BASIC, I intended to translate them into assembler. Therefore, I wanted to avoid trigonometric functions if at all possible.

Following on from a previous interest in methods of interpolation, I decided to apply linear interpolation to the problem. The method involves storing joint angles for a few points and interpolating between them to find the joint angles corresponding to intermediate points. To illustrate the method, assume the robot arm can only

move in one direction, that is, along the x-axis. Five joint angles must be considered for a five-degree-of-freedom arm, but the method is essentially the same for each joint angle.

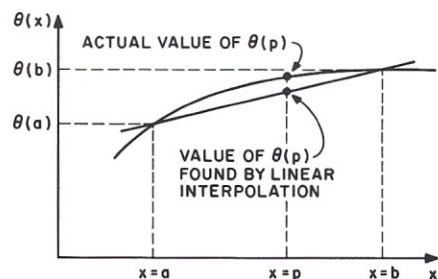


Figure 3. A graphic example of two-dimensional interpolation. The Cartesian coordinates of a particular point can be found by estimating the differences between two adjacent points for which position values are known.

Consider a joint angle theta, θ , which can be any one of the robot joint angles. Referring to figure 3, the joint angles are known for two values of x (x_a and x_b). To find the joint angle for an intermediate position, x_p , we use a formula which assumes that the function relating x to θ is a straight line:

$$\theta_p = \frac{(\theta_b - \theta_a)}{(x_b - x_a)} (x_p - x_a) + \theta_a$$

The value found by interpolation will differ from the true value. Providing the known points are not spaced too far apart, the accuracy will be adequate. In our case, the error could be neglected when interpolating between points spaced 5 cm apart. This method was readily generalised to three dimensions by applying the one-dimensional method seven times. Referring to figure 4, a, b, c, d, e, f, g, and h are the points where θ is known and point p is the position where we would like to know θ . We proceed as follows:

1. Assume a plane perpendicular to the x-axis which passes through p and cuts the line joining a and b to i. Use linear interpolation to find θ_i and in a similar manner θ_j , θ_k , and θ_l .

2. A line through p in the z direction cuts the line joining k and l at m. Use

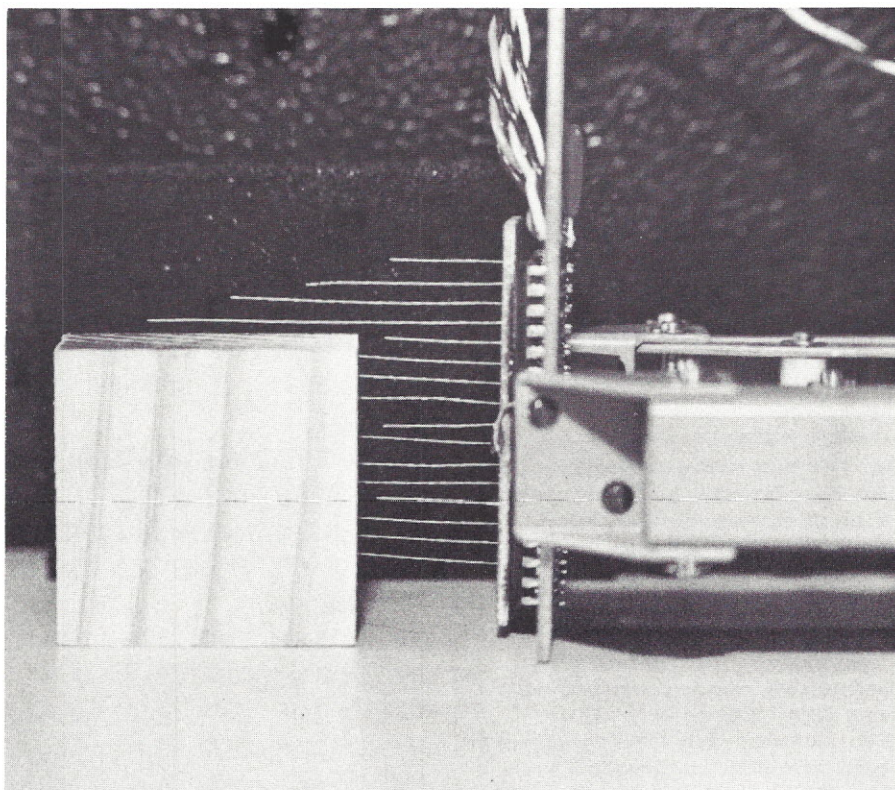


Photo 2. The array whisker sensor detecting a square block. The detected bit pattern is:

```
0 0 0 0
1 1 1 0
1 1 1 0
1 1 1 0
```

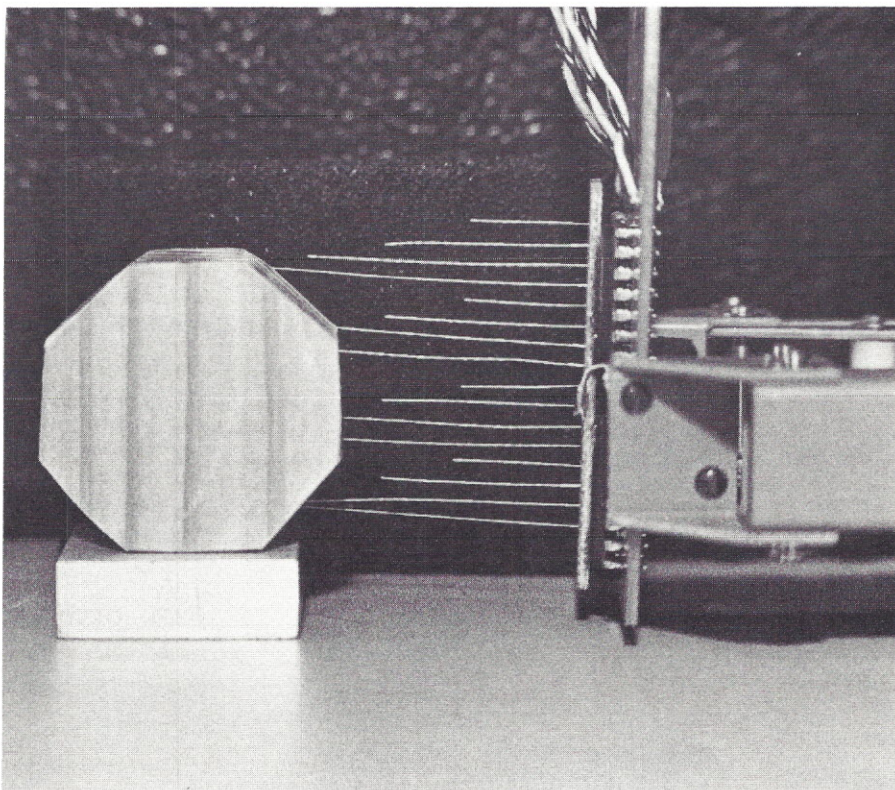


Photo 3. The array whisker sensor detecting an octagonal block. The detected bit pattern is:

```
1 0 0 0
1 1 0 0
1 1 0 0
1 0 0 0
```


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```

980 REM 3D INTERPOLATION SUBPROGRAM
990 REM *****
1000 REM
1010 REM CONVERTS CARTESIAN COORDINATES IN X,Y,Z
1020 REM INTO ROBOT JOINT ANGLES IN ARRAY T
1030 REM
1040 REM FIND COORDINATES OF KNOWN POINTS SURROUNDING P
1050 REM
1060 X1=INT(X) : Y1=INT(Y) : Z1=INT(Z)
1080 X2=X1+1 : Y2=Y1+1 : Z2=Z1+1
1090 REM
1100 REM NEXT 6 LINES ALLOW INTERPOLATION OUTSIDE THE
1110 REM VOLUME DEFINED BY THE KNOWN POINTS
1120 REM THE ACCURACY FALLS THE FURTHER YOU GO FROM
1130 REM THE VOLUME DEFINED BY THE KNOWN POINTS
1140 REM
1150 IF X<0 THEN X1=0 : X2=1
1160 IF X>=4 THEN X1=3 : X2=4
1170 IF Y<0 THEN Y1=0 : Y2=1
1180 IF Y>=2 THEN Y1=1 : Y2=2
1190 IF Z<0 THEN Z1=0 : Z2=1
1200 IF Z>=2 THEN Z1=1 : Z2=2
1210 REM
1220 REM CALCULATE DELTA X, DELTA Y, DELTA Z
1230 REM
1240 X3=X-X1 : Y3=Y-Y1 : Z3=Z-Z1
1250 REM
1260 REM CALCULATE THE 5 JOINT ANGLES
1270 REM KNOWN JOINT ANGLES ARE HELD IN ARRAY D
1280 REM WE INDEX INTO THE ARRAY TO FIND A JOINT ANGLE
1290 REM USING THE EQUATION:
1300 REM (X VALUE)+5*(Y VALUE)+15*(Z VALUE)+45*(JOINT NUMBER)
1310 REM
1320 FOR I = 0 TO 4
1330 T(I) = (D(X2+5*Y2+15*Z2+45*I)*X3+D(X1+5*Y2+15*Z2+45*I)*
(1-X3))*Z3
1340 T(I) = T(I)+(D(X2+5*Y2+15*Z1+45*I)*X3+D(X1+5*Y2+15*Z1+
45*I)*(1-X3))*(1-Z3)
1350 T(I) = T(I)*Y3
1360 T(I) = T(I)+(D(X2+5*Y1+15*Z2+45*I)*X3+D(X1+5*Y1+15*Z2+
45*I)*(1-X3))*Z3*(1-Y3)
1370 T(I) = T(I)+(D(X2+5*Y1+15*Z1+45*I)*X3+D(X1+5*Y1+15*Z1+
45*I)*(1-X3))*(1-Z3)*(1-Y3)
1380 REM
1390 REM TAKE INTEGER VALUE TO GIVE WHOLE NUMBER OF
1400 REM STEP MOTOR PULSES
1410 REM
1420 T(I)=INT(T(I))
1430 NEXT I
1440 RETURN

```

Listing 1. The three-dimensional interpolation subprogram written in BASIC.

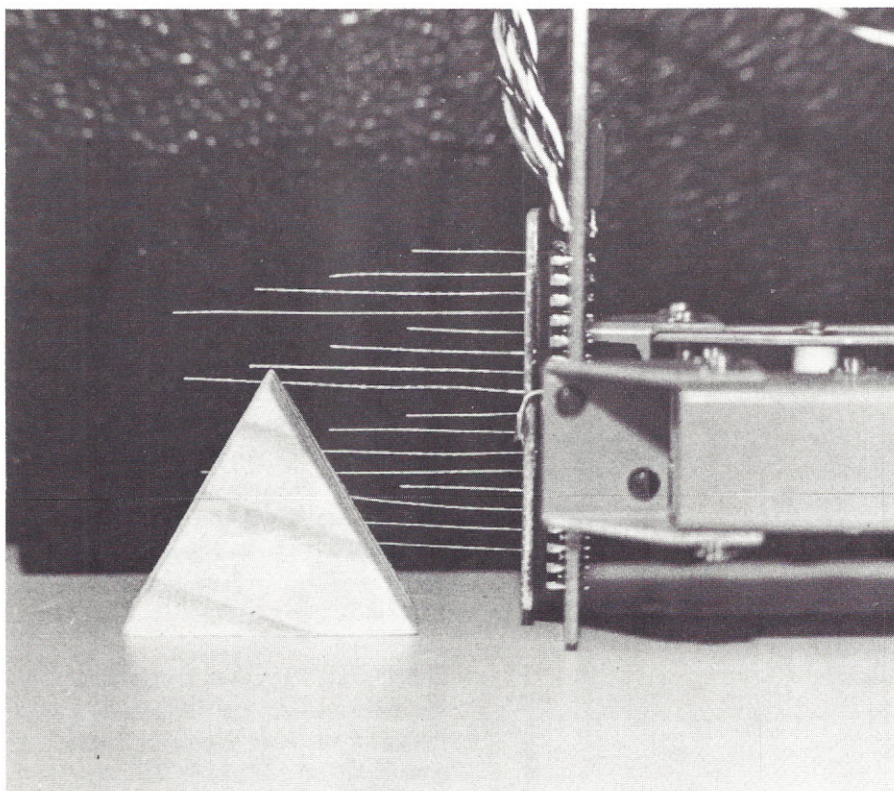


Photo 4. The array whisker sensor detecting a triangular block. The detected bit pattern is:

```
0000
1000
1100
1110
```

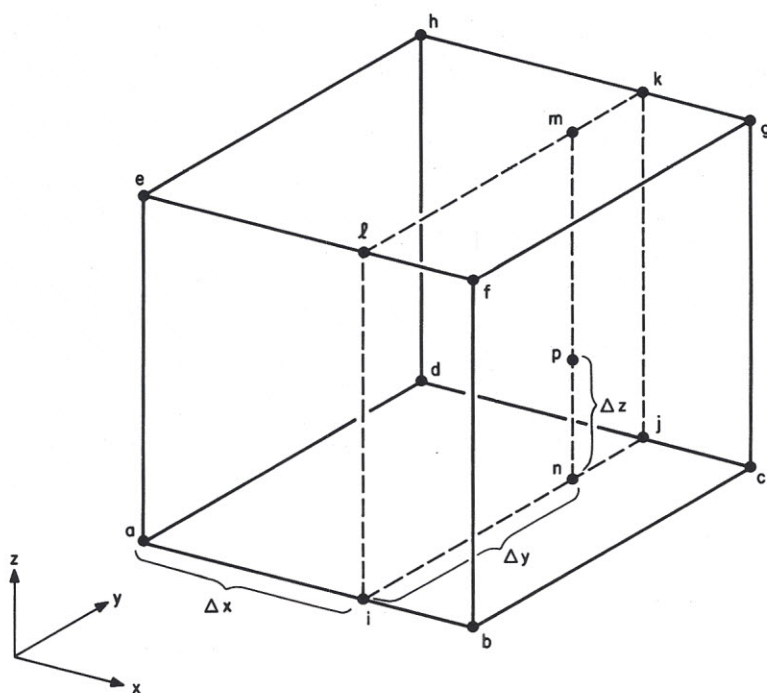


Figure 4. A graphic example of three-dimensional interpolation. By placing the known points in the xyz coordinate system unit distances apart, the formula for determining the point p can be written using only multiplication, addition, and subtraction.

linear interpolation to find θ_m and in a similar manner θ_n .

3. Use linear interpolation between m and n to find θ_p .

When equations for the seven stages of linear interpolation are combined, we have one equation which gives an estimate of θ_p in terms of known joint angles and Δx , Δy , Δz , the relative coordinates of p. This equation only involves addition, subtraction, multiplication, and division. If we assume that the scale of our xyz coordinate system is such that the known points are unit distances apart, then the equation for θ_p can be simplified to:

$$\theta_p = ((\theta_g \Delta x + \theta_h (1 - \Delta x)) \Delta z + (\theta_c \Delta x + \theta_d (1 - \Delta x)) (1 - \Delta z)) \Delta y + ((\theta_i \Delta x + \theta_e (1 - \Delta x)) \Delta z + (\theta_b \Delta x + \theta_a (1 - \Delta x)) (1 - \Delta z)) (1 - \Delta y)$$

After simplification, the equation does not require division. A BASIC subroutine to perform this calculation is shown in listing 1.

The subroutine uses stored joint angles for 45 points, five in the x direction, three in the y direction, and three in the z direction. To position the robot arm at a particular point, coordinates of the eight known points surrounding the unknown point are calculated. The three-dimensional interpolation equation is then used to calculate the five joint angles which will position the robot arm at the desired point p.

So far there has been no mention of the orientation of the robot gripper, only its position. The method of linear interpolation outline here works for only one gripper orientation. Each known point is recorded with the gripper in that orientation. I chose a vertical orientation for easy lifting and stacking. At the moment, I am working on the generalisation of this method to a range of gripper orientations.

Search Strategy. The whisker sensor can sweep through an area to detect objects if it can be maintained broadside-on to the direction of motion. Because the hunted object is stationary, the most efficient strategy to locate it is to perform a parallel grid pattern search. The search path is illustrated in figure 5. Search sweeps are performed in the y direction. After each sweep, the arm steps forward in the x direction. Since the Movemaster robot cannot be stopped in the middle of a move be-

tween two points, the computer executes a count loop to help find the y coordinate of the object.

Two counts are maintained, one runs continuously during the sweep and gives

a measure of the time it takes to perform the sweep. The second count stops when the whisker detects a cylinder. The two counts are used to find out how far along the sweep the cylinder was detected. This

distance is reduced by 1 cm to allow for bending of the whisker before contact is registered. Having found the xy coordinates of the point where the cylinder was detected, and allowing for the length of the whisker, the robot manipulator can be moved over the cylinder.

In order to improve the accuracy with which an object can be located, the robot closes its grip on the object (pats it) to locate it in the x direction, and then opens its grip, rotates 90 degrees, and picks it up in the y direction. This maneuver locates the object in the gripper to better than 1 mm. The cylinder is then stacked on the pile and the robot returns to the search at the place it left off. The stages of search and acquisition are illustrated in photos 5 through 9.

Conclusion. The system comprising sensor, interpolation algorithm, and search strategy work well and provide a fascinating demonstration of sensory feedback for a robot manipulator. Apart from the computer and robot arm, the demonstration cost very little and shows how even simple sensors can be used to good effect.

Andy Russell is a lecturer in the Department of Electrical and Computer Engineering at Wollongong University in Australia where he lectures in digital electronics and computers. His main research interest is in robotics—particularly in the area of tactile sensors.

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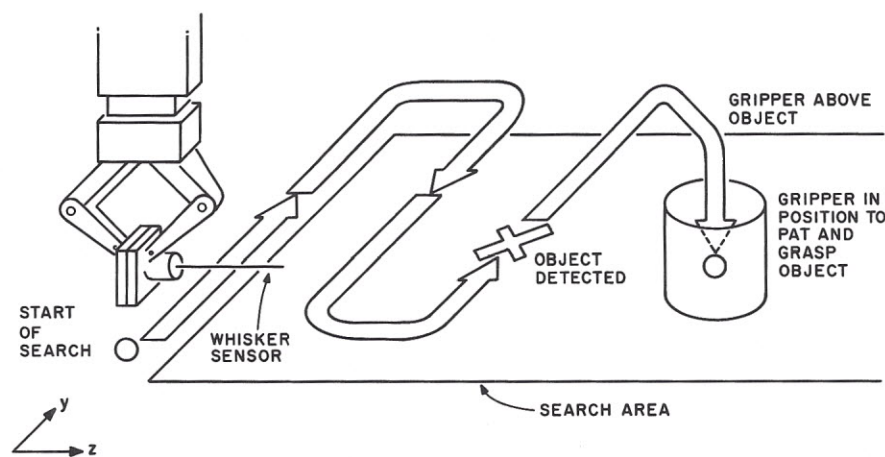


Figure 5. A parallel grid pattern search was used to locate the object on the table.

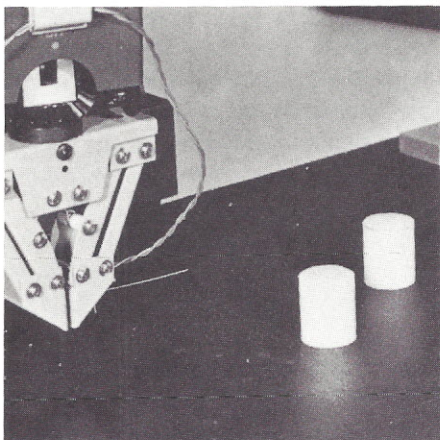


Photo 5. One cylinder has already been located. The Movemaster arm is now using the single-whisker sensor to locate the second cylinder.

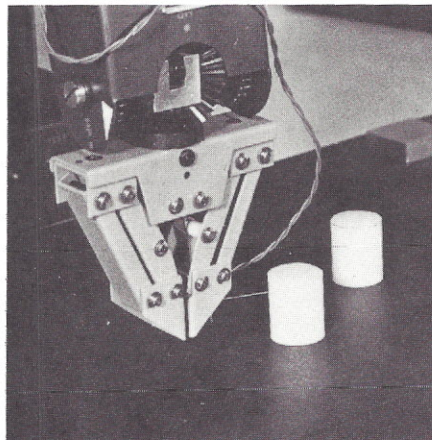


Photo 6. The whisker detects the cylinder.

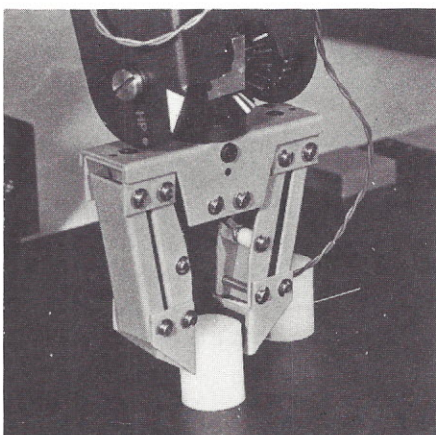


Photo 7. The Movemaster pats the cylinder to adjust its x-direction.

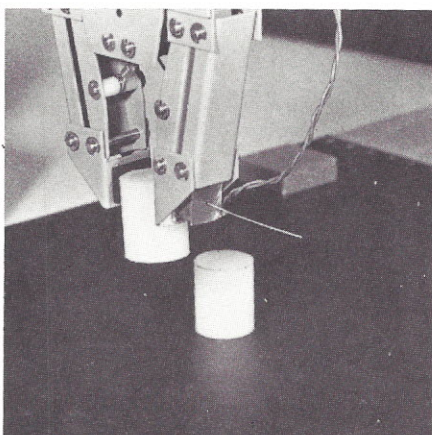


Photo 8. The gripper picks up the cylinder in the y-direction.

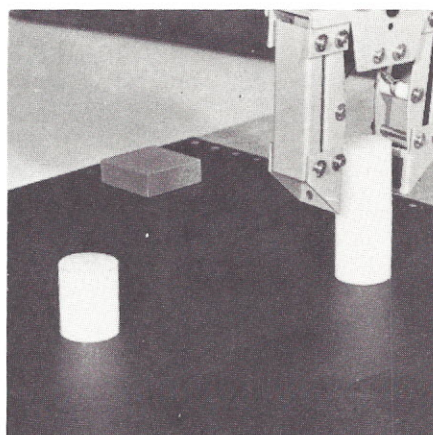


Photo 9. The second cylinder is stacked on top of the first cylinder.

Bipedal Balance

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Belfast, Maine 04915

A basic problem in the design of any legged walking machine is equilibrium, or balance. When searching for solutions to this problem, it is worthwhile to consider how living bipeds manage to stay on their feet. Then perhaps we can design a machine that works as well as a human, and in at least some of the same ways.

For machines with four or more legs, the usual approach to balance is to program the leg movements so that three or more feet always remain on the ground. There can then always be a "polygon of support" enclosing the projection of the machine's center of gravity on the ground. As long as this projection stays within the polygon of support, no matter how it wavers, the machine cannot tip over. Only when the polygon disappears—as it does in the faster gaits which put fewer than three feet on the ground at a time—must the machine use other ways to preserve equilibrium.

Bipedal machines cannot always have a polygon of support. Even when merely walking, there must be times when only one foot is on the ground, and never are more than two feet on the ground. This does not mean that the machine must balance on one or two points. The feet can be flat and broad to provide a large supportive area. The machine must, however, keep the projection of its center of gravity within the limited "area of support" stamped out by one or two feet.

This constraint is too limiting. Random disturbances inevitably shift the center of gravity out of the stable area. But more importantly, the center of gravity is forced to shift outside the stable area of support each time the machine shifts its weight from one foot to the other. The machine necessarily experiences tipping moments. How then can it stay upright?

Animals commonly anticipate imbalances. That is, each footfall in a gait counteracts a tipping moment. This produces a dynamic equilibrium, rather than a static equilibrium. Bipedal animals rely

even more on corrective movements. They constantly counteract tipping moments, either by moving their feet or by shifting their centers of gravity. They do both so skillfully and smoothly that the corrective movements are rarely noticeable. Bipedal machines do neither very well. They seem limited to slow, careful, deliberate movements. Some must even keep both feet on the ground at all times, their motion limited to a slow, shuffling gait.

A number of researchers are working on giving machines the capability for lifelike corrections and balance. Marc Raibert and his colleagues at the Robotics Institute of Carnegie-Mellon University in Pittsburgh have built a computerized pogo stick powered by compressed air. This one-legged "walking" machine hops all over their lab, and it keeps its balance quite successfully. Each time it lands, its computer measures just how far out of balance the

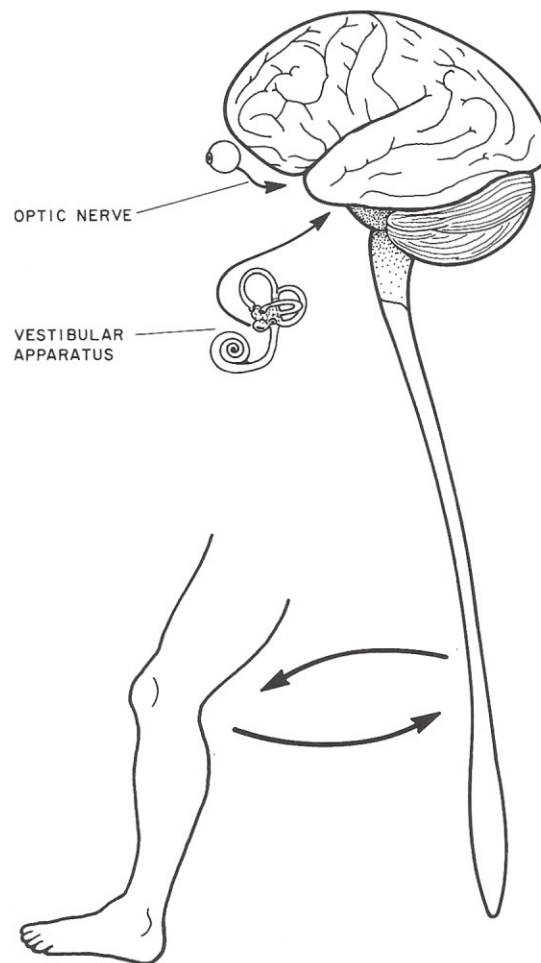


Figure 1. The human brain and spinal cord.

machine is. A servo then corrects any tipping moments with countertorques, taking advantage of friction between foot and floor. Some imbalances can be corrected by placing the foot out of the line of motion—by “propping” against a lean or spin.

Animals use both methods to correct their imbalances, but they don't use a central computer to calculate and command corrective actions. Instead, they use a form of distributed control. They do not use the thinking or other high-level parts of the brain. They use *reflexes*, automatic motor responses to specific sensory stimuli, which are wired into low-level parts of the central nervous system. Many reflexes do not involve the brain at all. Instead, they require only a few nerve cells in the spinal cord, that column of nervous tissue shielded by the backbone.

The simplest reflex is the *stretch reflex*. It is a biological feedback circuit which holds a muscle at a particular, set length. This results in joints being held at specific angles. The stretch reflex depends on sensors buried deep within muscles. These sensors are the muscle spindles. Each mus-

cle spindle is a bundle of modified muscle fibers enclosed in a tapered sheath. Motor nerves enter the sheath to control the spindle fibers, and sensory nerves leave the sheath to convey signals to the spinal cord.

Motor commands from the spinal cord to a muscle reach both muscle fibers and spindle fibers, so that the two contract in parallel. As long as they remain in parallel, the spindle's sensory nerves carry no signals. The spindle sensor's zero point is set by its own contraction to match the degree of muscle shortening ordered by the nervous system.

However, if the muscle is stretched beyond its “proper,” commanded length, the spindle is stretched beyond its zero point. The spindle then generates signals in its sensory nerves. These spindle signals report the degree and rate of change of the unintended stretch to the spinal cord. Motor cells in the spinal cord then command the muscle to contract further and return to the initially set length. This is what happens in the classic knee-jerk reflex. The doctor's tap on the tendon just below the knee cap stretches the thigh muscle beyond the length set by the ner-

vous system. The thigh muscle's spindles report the deviation to the spinal cord, whose cells then command the thigh muscle to contract. The contraction produces the typical reflex kick.

The same thing happens when someone passes you a book. You hold one hand out, chest-high. When the book lands in your hand, the added weight causes your hand to sag. This motion stretches the biceps muscle which activates the spindles' sensory nerves. The spindles report, and the spinal cord orders the biceps to contract. As a result, your hand rises to its previous position.

The stretch reflex is also involved in maintaining erect posture. It helps the leg muscles keep the legs extended against the pull of gravity and the transient loads induced by the impacts of steps. It helps the muscles of torso and hips correct for sway and lean; it thus helps keep the projection of the body's center of gravity under the feet.

A second important reflex appears in the *flexion reflex*. In its simplest form, it is a response to sensors in the skin. When these sensors register pain, they report to the spinal cord. Nerve cells there command the muscles that bend or flex the leg to contract. The result is that the pained patch of skin is jerked away from the source of its agony. You see the flexion reflex in action when you step on a tack or touch a hot pot. Your foot or hand jerks away from the pain well before you consciously feel the pain. This demonstrates that the neural circuitry responsible for the reflex is local, in the spinal cord. It does its job while the pain signal is still on its way to the brain.

What help is the flexion reflex in the problem of balance? Because of the way the spinal cord's nerve cells are wired together, the flexion reflex is generally accompanied by the *crossed extension reflex*. Even as one leg flexes, the other extends or stiffens. As the spinal cord sends commands to the flexor muscles of one leg, it also sends commands to the extensors of the other. It is as if fluid withdrawn from one hydraulic piston were supplied to another, so that the two pistons worked 180 degrees out of phase with each other.

When a biped is standing on two legs, a flexion reflex can yank one foot off the ground. The accompanying crossed extension reflex strengthens the support supplied by the other leg. If the biped is walk-

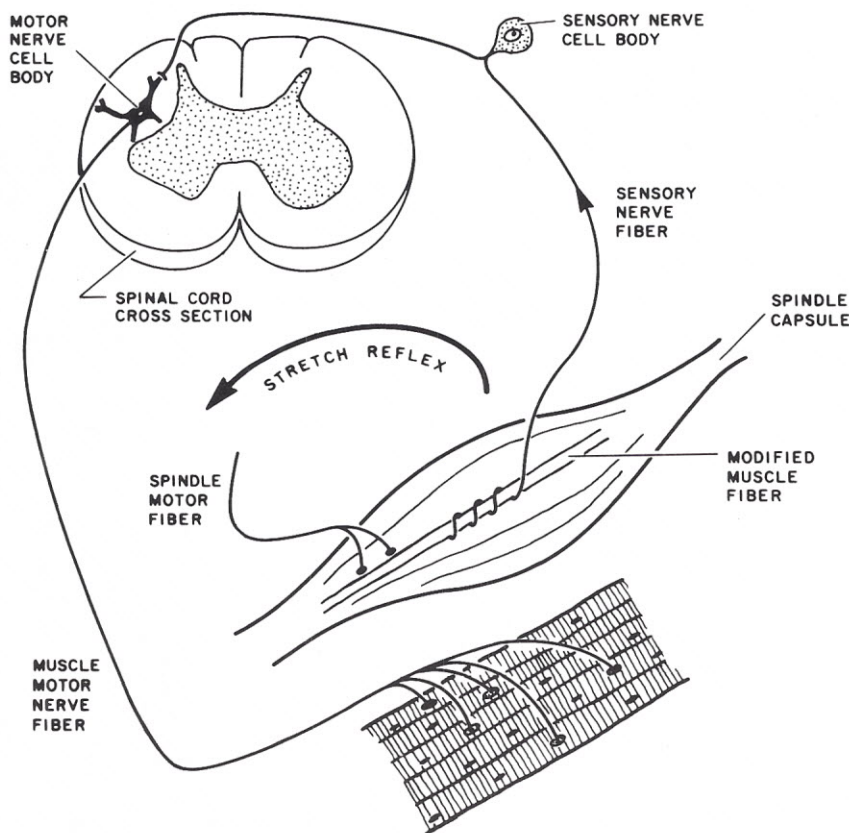


Figure 2. The stretch reflex holds a muscle at a particular, set length.

ing, and steps on a stone, the flexion reflex will try to yank the single foot on the ground into the air. The crossed extension reflex will get the other foot down in time to prevent a fall.

Unlike the circuitry of the stretch reflex, where sensory nerves report directly to motor nerve cells, the flexion and crossed extension reflexes involve an intermediate nerve cell. The sensory nerves report to an *interneuron*, which commands the motor nerve cells to activate the muscles. The existence of this interneuron means that higher levels of the nervous system, such as the brain, may also activate the pair of reflexes. This actually seems to happen during locomotion; as one leg flexes, the other must extend. Reflexes may thus simplify the problem of motor control in general by reducing the number of separate actions the brain must coordinate.

Skin sensors are also involved in the *placing reflexes*. They help the feet avoid holes and humps and find level ground to rest on. Humans have these reflexes, but they are more apparent in lower animals such as cats. To demonstrate this reflex, blindfold a cat and hold it in the air. Let the edge of one paw gently brush the edge of a table. The cat will lift the paw and place it squarely on the table. The cat does not need the highest levels of its brain to do this, for a cat whose cerebral cortex has been removed still has placing reflexes.

The placing reflexes are well suited to establishing stable footing. The stretch reflex is used to hold a posture once it is set, and for correcting small deviations. The crossed extension reflex seems best for keeping a lurch from turning into a fall. Yet all can fail to keep a biped upright. Other reflexes must come into play. The most important of these other reflexes are the *vestibular reflexes*, whose sensors lie in the inner ear.

The parts of the inner ear concerned with balance are the semicircular canals, the utricle, and the saccule. The semicircular canals are three hollow hoops set at right angles to each other and filled with fluid. At the base of each hoop is a bulbous ampulla. The ampulla is blocked by a gelatinous cupula in which are embedded the hairlike cilia of the sensory cells. Any rotation of the head in the plane of a hoop sets the fluid in the hoop in motion. The moving fluid deflects the cupula and bends the hairs of the sensory cells. As the hairs bend, the cells generate nerve signals

which tell the nervous system which way the head is turning.

The utricle and saccule also contain patches of sensory cells. These cells too have cilia, which are embedded in a gelatinous mass containing granules of calcium carbonate, the statoconia. The utricle and saccule respond to gravity and to linear accelerations, both of which act on the statoconia to bend the sensory cells' cilia. The cells tell the nervous system which way the head is tipping or in which direction it is beginning or ending a movement.

The semicircular canals, utricle, and saccule are all basically accelerometers. They can easily be mimicked in a machine. They work together to maintain balance by triggering reflexes that compensate for leans,

tips, spins, and falls.

The vestibular reflexes can be demonstrated in a four-legged animal by standing the animal on a platform that can tip from side to side and from front to back. If the platform tips down in front, the animal's forelegs extend and its hindlegs flex. If the platform tips down in back, the forelegs flex and the hindlegs extend. If the platform tips down to one side, the legs on that side extend and those on the other flex. All these motions tend to keep the body level. Other reflexes, which relate neck bends to vestibular stimuli and to limb flexion and extension, help keep the head level.

The tippable platform is also useful for demonstrating the reflexes in humans. People respond to a sideways tip by flexing the

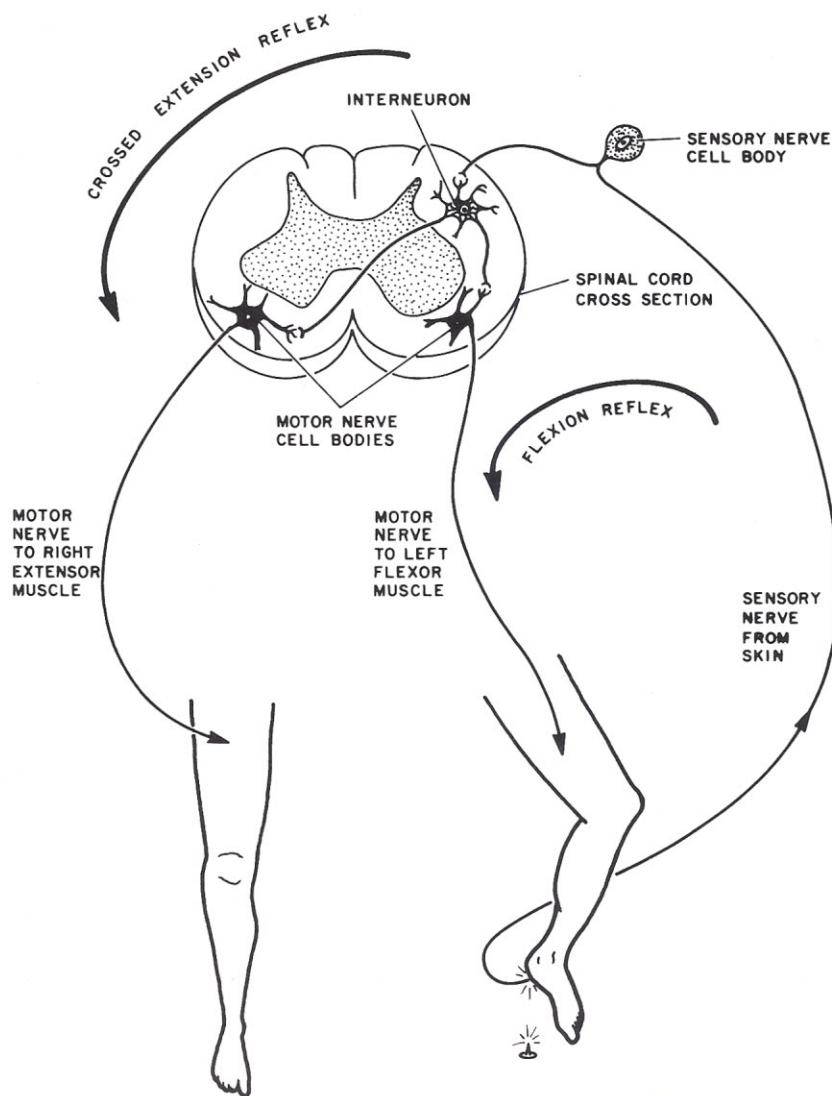


Figure 3. The flexion and crossed extension reflexes are useful for coordinating two legs.

uphill leg and extending the downhill leg. During a forward tip, they lean backward; if the tip is extreme, the person may take a step, setting one leg forward, extended, while the other, now a hind leg, flexes. People respond to a backward tip by leaning forward, or by stepping backward. In each case, the reflex keeps the body straight up and down and balanced on its feet.

Humans also respond with their arms. When they tip to one side, they extend the arm on that side. When they tip forward, they flex both arms, bringing them up in front of the face. When they tip backward, they extend them backward. In each case, the reflex seems to prepare the body to catch itself in case the tip turns into a fall. Here, the reflexes seem to serve self-protection more than balance.

Visual reflexes also help bipeds stay upright. The brain compares the visual field against the signals from the vestibular sensors and from pressure sensors in the soles of the feet. The brain can detect leans and sways just by changes in the orientation of the visual field on the retina. The brain can maintain equilibrium by relying on vision alone, but vision seems less important than the vestibular senses. That vision plays a significant role is obvious when we are blindfolded or in the dark. Without the aid of vision, we are more likely to stagger. Yet the blind do without it quite well. In comparison, when the vestibular senses go awry, it can take a long time to learn to use vision alone.

The various reflexes that contribute to balance inevitably interact, and balance is the result of their interplay. This interplay takes place at the level of the motor neuron, often called the "final common path," which commands the individual muscles to contract. Various commands, including those for voluntary movements, reach the motor neuron along various paths. Some commands are strong. Some are weak. Some are excitatory. Some are inhibitory. The motor neuron sums them all and orders the muscle to contract only when the sum is above a certain level. Gradations in the strength of a muscle's contraction arise because each muscle is commanded by a pool of many motor neurons. Since each neuron receives its own mix of commands, not all members of the pool order contractions at the same time, except in the case of the strongest contractions.

The balance achieved by interacting

reflexes is smooth and flexible. It is equal to the demands of walking, running, dancing, and carrying wine glasses full of nitroglycerin, even on rough ground. It does not distract the brain from other tasks.

The living biped's ability to balance is the envy of the roboticist. Yet it should be possible to build a legged machine that can move quickly, smoothly, and gracefully, and does not need all its brain to control its movements. The trick may be to imitate the methods of life. Have the central computer issue only a rough locomotor guide, a sequence of limb activations, or even a single activating command to a subsidiary control center. Give each limb its own control circuitry, analogous to the neuronal cir-

cuitry of the living biped's spinal cord. Design this local circuitry to respond in set, corrective ways to the signals from sensors for limb configuration, gravity, acceleration, and "skin" pressure, and allow the signals to interact in determining the proper responses of the machine's servos.

The result will be a machine that uses reflexes. It will correct imbalances quickly and smoothly, and its computer will be free to handle other tasks.

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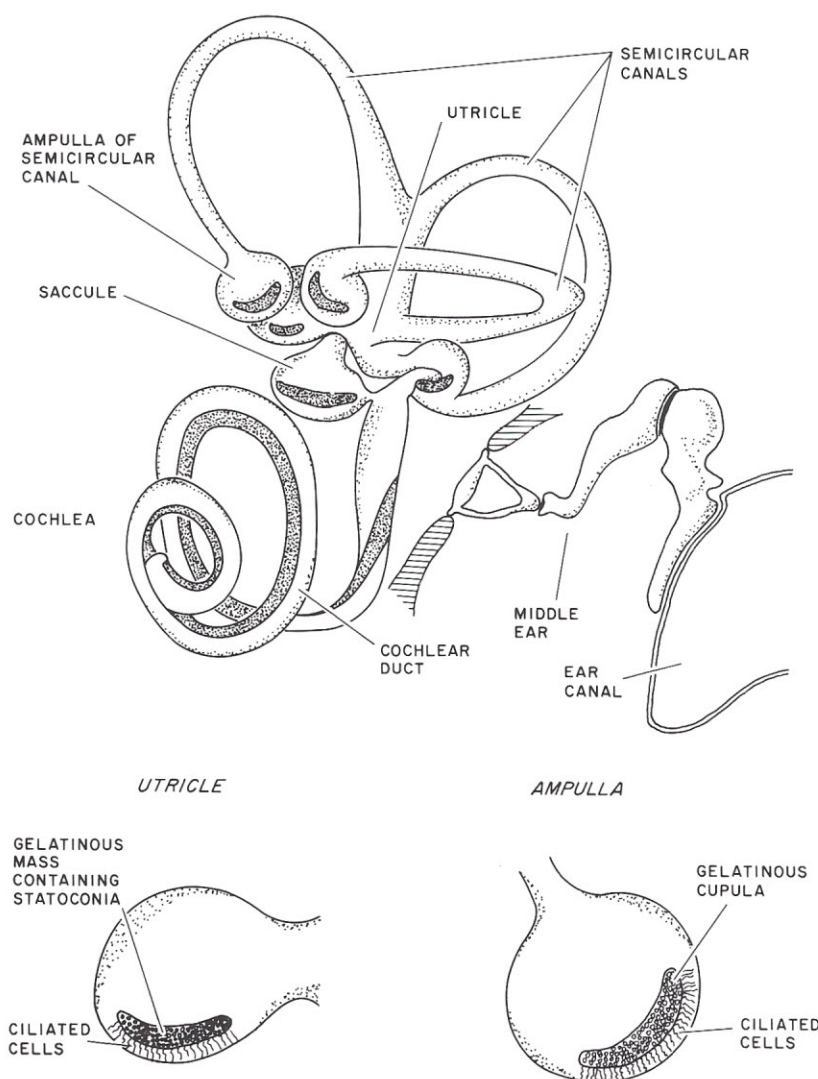


Figure 4. The vestibular apparatus consists of the semicircular canals, the utricle, and the saccule. All are contained in the inner ear.

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Robot Warehouse

Russ Adams
3008 Mosby Street
Alexandria, Virginia 22305

A robot does not have to be a single piece of hardware. Sometimes it can be an entire building. Take the device described in patent number 4,395,181 issued to Weston R. Loomer on July 26, 1983. The patent (owned by Litton Systems, Inc., Florence, Kentucky) discloses a system for automatically transporting loaded pallets around tracks in a warehouse.

The automated warehouse storage system has a robot vehicle which transports loaded pallets along tracks. The vehicle has a main body and support wheels on each side. A lift mechanism raises pallets above the track level for transportation. The pallets can be lowered onto support surfaces formed on the tracks for storage.

The main vehicle body has a guide wheel at each corner. These guide wheels sense abrupt changes in the track's direction before the load-bearing vehicle wheels reach that location.

Power is supplied by a cable leading to a central power center. The cable is wound or paid out on a drum mounted to the vehicle's chassis. This drum has a single helical groove which receives the cable.

Figure 1 shows the automated storage system disclosed. The system is made up of a storage rack formed by horizontal rails (11) and supported by vertical columns (12). Each pair of rails forms a storage bay along its entire length. The storage rack can consist of a single level or can be multitiered.

The upper surfaces of each rail are designed to support loaded pallets. Each rail also has a lower surface (15) for supporting the wheels of pallet-carrying vehicles (20). The vehicle can, when empty, slide under pallets resting on the upper surfaces of the rails.

Perpendicular to the pairs of pallet supporting tracks is another pair of rails.

These rails form a pallet transfer track. Several pallet transfer carriages (30) move along the track. These transfer carriages each have an area for receiving the pallet vehicle and transporting a pallet.

Electric power is supplied to the transfer carriage by a cable (32) attached to a central power source. Power is supplied to the pallet vehicle by another cable (33). This cable is wound around a drum mounted on the pallet vehicle. It is wound or paid out as the pallet vehicle moves along the pallet storage tracks.

The transfer carriage movement and operation is controlled by a central logic system. This system also transmits commands to the logic system on board each pallet vehicle.

As shown in figure 2, each pallet vehicle has a motor (21) for driving wheels (19). A second motor (22) operates the pallet lifting mechanisms (23) which raise and lower the pallets.

Figure 4 shows the cable drum (34) with its helical grooves. The cable is wound onto the drum along the grooves. This cable, in addition to carrying power, is also connected to the logic system (36). The drum's construction automatically guides the cable into its proper position as the cable is wound. This eliminates complicated feeding mechanisms which might otherwise be required.

When a pallet containing material needs to be retrieved, the appropriate pallet vehicle is given a command to move along the pallet supporting tracks to a location under the desired pallet. The location of the vehicle would be determined by tracking how much cable is left on the drum. When the correct location is reached, the vehicle's lifting mechanism is activated and the pallet is lifted above the track surface.

While the pallet vehicle is retrieving the pallet, the appropriate transfer carriage is moved to the end of the appropriate pallet

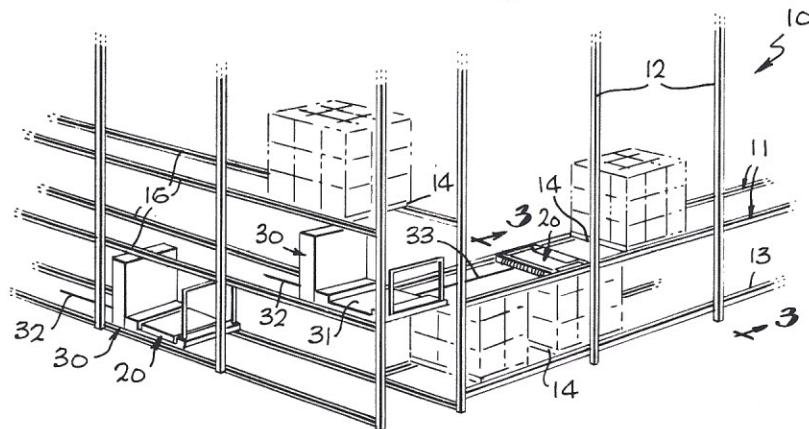


Figure 1. The transport vehicles move along storage rack tracks.

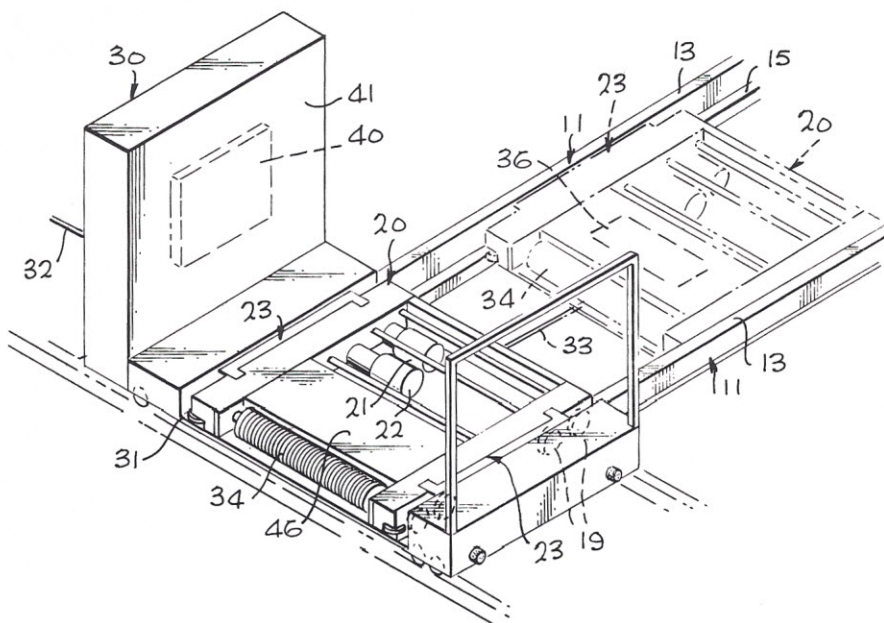


Figure 2. A close-up view of the transport and pallet vehicles.

track. The pallet vehicle moves with the pallet along the track and into the space provided on the transfer carriage. The lifting mechanism is again activated and the pallet is lowered onto the transfer carriage's pallet supports. The pallet vehicle slides out from under the pallet and off the carriage. The carriage then transports the pallet to the front of the storage rack.

Copies of this patent are available from the U.S. Patent and Trademark Office for \$1.00 each. Orders for patents should be sent with payment to: Commissioner of Patents and Trademarks, Washington, DC 20231.

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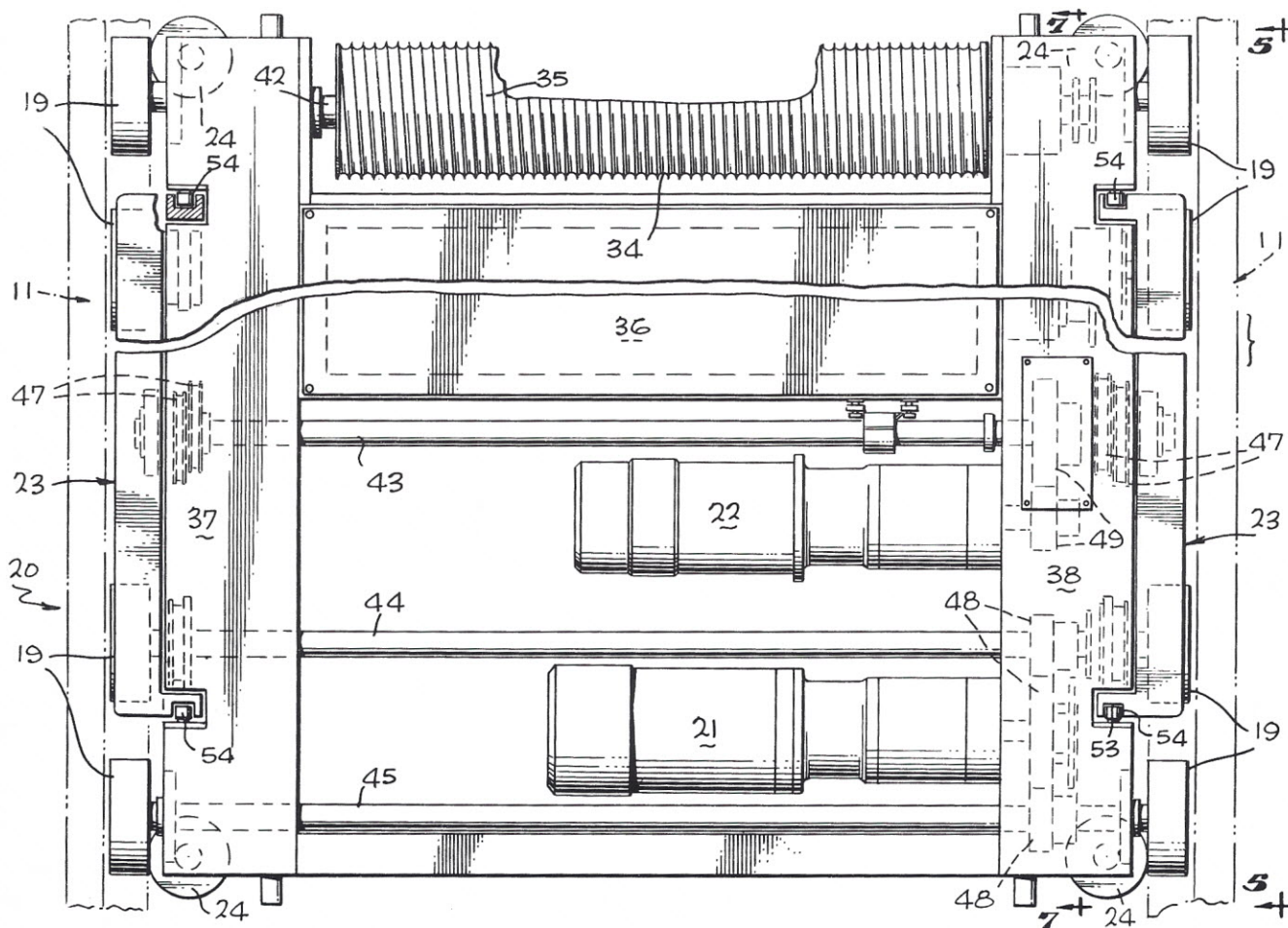


Figure 4. Helical grooves are built into the cable drum. These grooves automatically guide the cable into the proper winding position.

Armega 33

Part II: The Electrical Components

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Number 301
Alexandria, VA 22304

The following sections discuss Armega 33's electrical and electronic aspects. These two aspects are intertwined in any actual sequence of arm movement and control.

Power Supplies. All power for the Armega 33 is provided by two regulated 12 VDC power supplies rated at 2.5 A for continuous operation and having a 5 A surge capacity. One of the two units is dedicated to powering the servomotors. The other is used to power relays and the solid-state electronics. The two power supplies are not interconnected. Power required by individual servomotors is normally less than 1 A but may rise to more than 2 A in the case of extreme loads on the shoulder servo. Combined maximum loads created by relays and integrated circuits may approach 0.5 A. Separate power supplies ensure that fluctuations in power requirements from one source do not affect the other's performance.

Manual Controls. There are two lessons which come very early in working with an arm driven by lead screw servos. First, you must have some method of manually controlling arm movement independently from the computer-based control system. Second, you had better equip all moving elements with reliable limit switches. This is a useful approach for any kind of drive system, but it is vital for lead screw servos.

Limit switches are required by those numerous instances in which either under manual or computer control, arm elements are inadvertently driven past their normal operating limits. In other types of drives, this may only mean a stalled drive motor. With lead screw servos it is much more likely to mean that something important

is either going to be bent or broken. The shoulder servo in Armega 33, for example, develops a thrust of up to 30 pounds (13.6 kg) before it stalls.

The only way the arm elements can be moved is by means of the servomotors. The servos lock the driven elements into place whenever they are at rest. This dictates some kind of manual switch console which will function conveniently even when the arm is completely disconnected from the computer.

The manual switch console I developed for Armega 33 is shown in photo 7. Each of the six switches controls one of the arm's six servomotors. The single switch in the bottom row moves right and left and controls body rotation clockwise or counterclockwise. The three switches in the center row move backward and forward and control *lifting* or *lowering* movements of three arm elements: shoulder (left switch), elbow

(center switch) and wrist pitch (right switch). The two switches in the top row both move right and left. The left-most switch controls wrist rotation, clockwise or counterclockwise, the right-hand switch controls opening and closing the hand. The 44-pin edge connector shown at the end of the manual console cable connects the console to the main circuit board and is typical of the connectors used to connect both the arm cable and the input/output board cable to the main circuit board.

Figure 2 illustrates the power and control elements associated with a "typical" servomotor. In a complete wiring diagram, these basic elements are essentially repeated six times over. The general arrangement of figure 2 is as follows.

The manual switch console is shown at the lower left. It is connected to the main circuit board, shown at the center, which in turn is connected to an 8-bit parallel in-

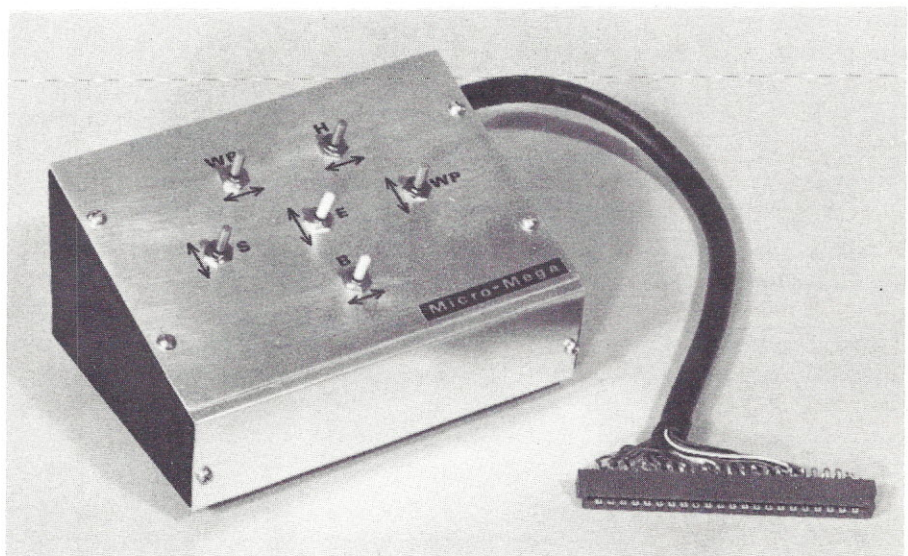


Photo 7. Manual control console. The arm can be easily switched from computer control to manual control.

put/output board, shown at the right. Also connected to the main circuit board at the top is the wiring associated with a typical servomotor, in this case, the elbow servo. The major elements shown are connected to the main circuit board through 44-pin edge connectors so that all main components can be easily disconnected. The connecting cable for the manual switch console is 12 in. long (30.5 cm) and the

cable to the input/output board is 60 in. long (1.5 meters). The wire bundle which emerges from the base component of the arm extends 16 in. (41 cm) from the base to the main circuit board.

Double-pole/double-throw switches with a *center-off* position are used on the manual control box. The switches are used to reverse the polarity of the 12 V servo power at the motor terminals and thus

reverse the servomotor's direction of rotation. (Figure 2 shows only one typical switch of the six actual switches on the console). Although the simplest arrangement would require only two power leads to each servo, my design uses four power leads for each motor. The extra wires are required to make the limit switches operate correctly.

The two limit switches which check the

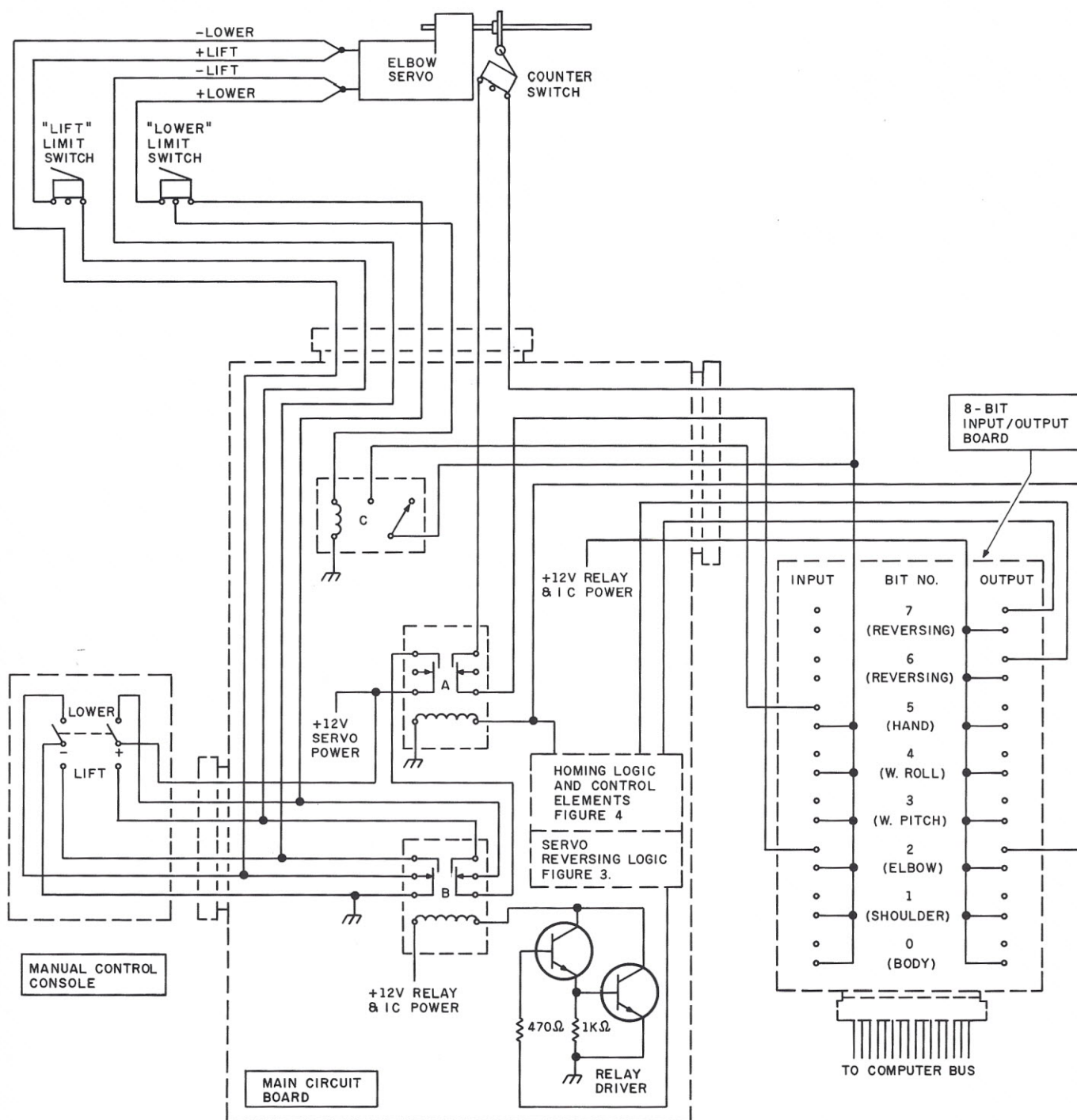


Figure 2. Typical servo power and control elements. This basic design is duplicated for each servomotor on the Armega 33 arm.

forearm movement relative to the bicep are shown at the top of figure 2. The left switch interrupts the servo power when the forearm reaches its maximum *lifting* position, the right switch cuts the power when the forearm reaches its maximum *lowering* position. Limit switches must do more than just stop all movement at the limit of travel. They must allow the servomotor to be reversed. The four-wire power lead arrangement permits this.

Relay Servo Switching. Computer-controlled relays are used for switching servo power. While a solid-state device could have been used, current flows in excess of 2 A tend to complicate matters. Currents at this level pose no problems for relays.

When the computer is in control of the arm, the B relay, shown near the bottom of the main circuit board in figure 2, operates as an almost exact counterpart of the manual console switch described earlier except that the relay has no *center off* position. Relay B is a double-pole/double-throw relay with a 12 V coil. In the position shown in figure 2, relay B drives the elbow servo *forward*. For this servo, forward is in the *lowering* direction. When relay B is activated, the servo direction is reversed. Note, however, that the positive armature of relay B is not connected to the +12 V servo power source unless relay A is also thrown. Relay A is an identical 12 V double-pole/double-throw relay which carries out two functions. When thrown, the left armature of relay A connects the +12 V servo power source to relay B and at the same time closes the open circuit in one of the leads from the counter roller switch of the elbow servo. This permits counting pulses from the elbow servo to reach the input side of the 8-bit input/output board.

Typical servo relay switching can be summarized as follows: to drive a servo *forward*, simply throw relay A; to drive a servo in *reverse*, relays A and B must be thrown.

Thus far, we have discussed most of the elements shown on the main circuit board in figure 2. The exceptions are the *homing* relay C, the *drive* circuit for relay B, and the box which refers to figures 3 and 4. We will explore these elements later.

Computer Controlled Arm Movements. The 8-bit input/output board shown schematically at the right in figure 2, was pur-

chased assembled. It is typical of digital interface boards available from a number of suppliers. The board accommodates one byte (eight bits) of output information from the computer and accepts one byte (eight bits) of input data. The particular input/output port number is set by means of an eight-position switch. The port chosen in this particular case was number three.

When using the BASIC programming language (from a Radio Shack TRS-80™ computer), output commands to the interface board take the form of OUT 3,64. Commands to read input signals take the form A=INP(3).

As indicated in figure 2, the 8-bit interface board is connected to the computer bus through a 40-conductor ribbon cable. Photo 8 shows the bottom side of the interface board. The two rows of eight toggle switches, one on each side of the board, were added to aid the manual testing of control logic and relays. Each pair of out-bit or in-bit contacts can be closed with a switch as well as through commands from the computer. The eight output bit positions are in the row on the right side of the board with the nearest bit being bit 0

and the most distant being bit 7. The input bit positions appear in the same order in the row at the left side of the board. When a binary 1 is sent to one of the output bits, it activates a reed relay which closes two contacts. Figure 2 shows that one contact of each output reed relay is connected to the +12 V relay and integrated circuit power source. The other relay contact at out-bit 2 is connected directly to the coil of relay A. Accordingly, when the reed relay at out-bit 2 closes, the +12 V source is switched to the coil of relay A, relay A is thrown, and the elbow servo moves the forearm in the forward direction.

The BASIC command is simply OUT 3,4. The binary equivalent of 4 is 00000100. When this pattern is placed on the output byte, the third bit (bit 2) receives a binary 1. This closes the reed relay. Reversing the servomotor is slightly more complicated. If six of the eight bits are used to switch each of the six servos forward, only two bits (bits 6 and 7) remain to control all the reversing chores. To accomplish this requires some decoding logic. Figure 2 shows that the individual leads from out-

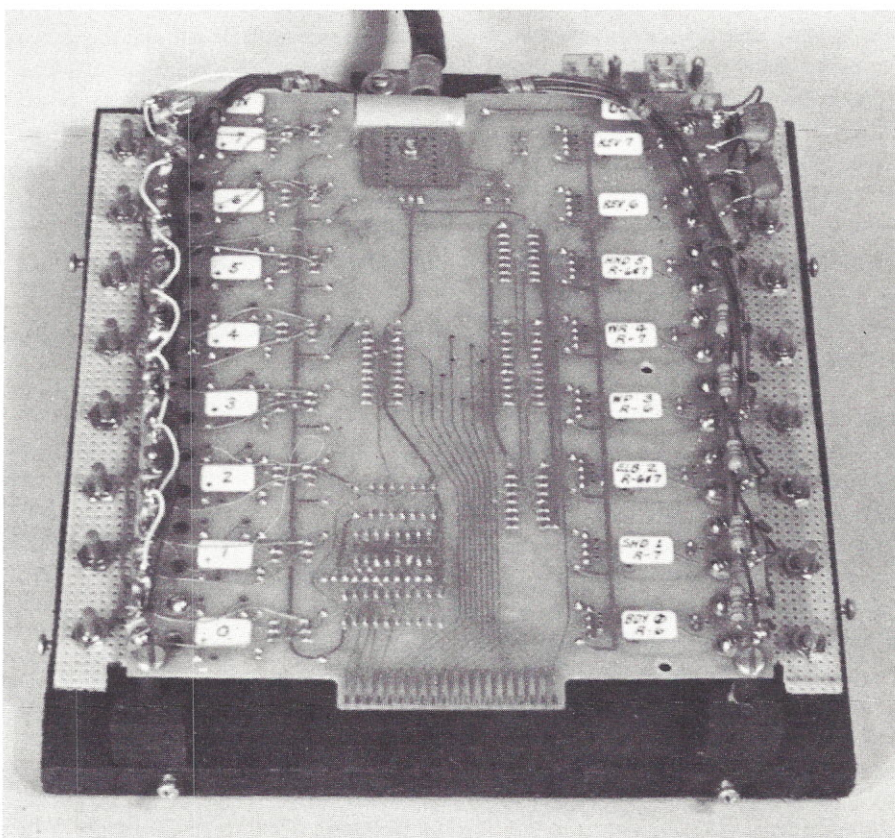


Photo 8. The 8-bit input/output circuit board is the interface between the computer and the arm. A total of 15 different control commands can be transmitted to the arm using only the eight output-bits (right side). Positive feedback, confirming all arm movements, is received through the eight input-bits (left side).

bits 6 and 7 do not go to relay coils but instead to the box which references figures 3 and 4.

Figure 3 is titled *Servo Reversing Logic*. It is a simple logical decoder which permits out-bits 6 and 7 to reverse each of the six servomotors. The circuitry described decodes an 8-bit value into one of several operations. Reversing the body rotation servo requires a binary 1 at both out-bit 0 and out-bit 6. Reversing the elbow servo requires binary 1s at out-bits 2, 6, and 7. The computer-control, servo-command table is shown in table 2.

The outputs of the AND gates in figure 3 are labeled Reverse Body, Reverse Shoulder, etc. However, the logic-level output from the AND gate is inadequate for activating relay B. To provide enough current, the AND gate outputs are connected through amplifiers or drivers of the type shown at the lower right of the main circuit diagram in figure 2. The driver circuit uses two transistors and provides more than enough current for relay B.

Most of the preceding descriptions centered around figure 2 were based on the operation and control of a single servomotor. Armega 33 actually has six servomotors. Photo 9 shows the completed main circuit board. Two rows of six relays each are visible at the upper right of photo 9. Relays in the top row correspond to relay A in figure 2, and the bottom row to relay B. The small board just below the lower row of relays contains the driver circuits for each of the relays in the bottom row. The integrated circuits at the upper left of photo 9 include the two quad two-input AND chips used for the reversing logic represented in figure 3.

Closed Loop Arm Feedback. The preceding sections have outlined the manner in which arm elements are driven in either forward or reverse directions under computer control. Not yet covered is how servos are stopped by the computer, and how the computer knows *when* to stop. Stopping a servo with a BASIC command is very simple. For example, if the program initiated a clockwise body rotation with an OUT 3,1 command, an OUT 3,0 command will stop the motion. OUT 3,0 opens any A or B relays which are closed and thus halts all servo motion.

The question of knowing *when* to stop takes us back to figure 2 and the function of the counter switches attached to five of

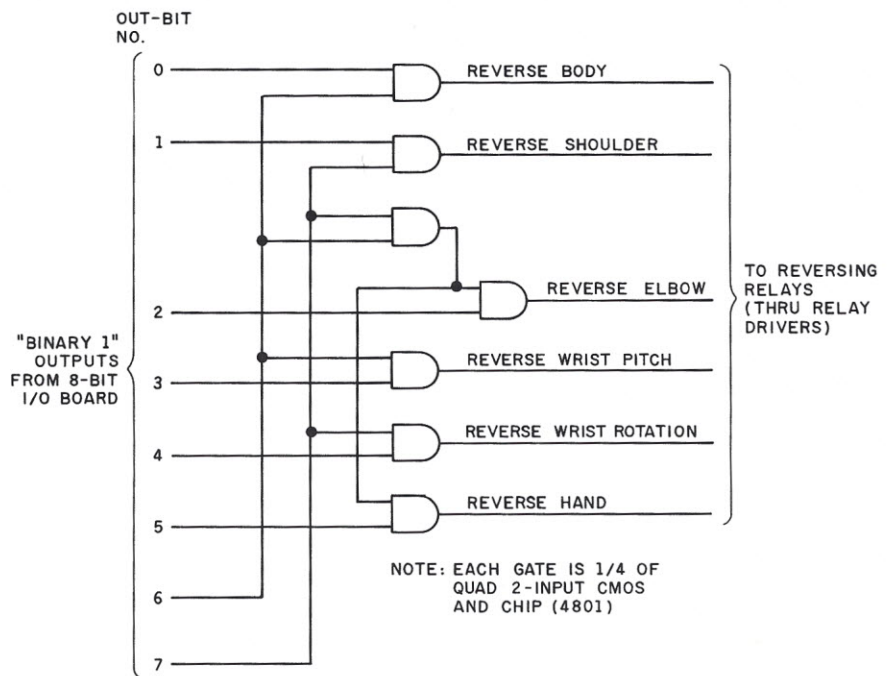


Figure 3. Servo reversing logic. This simple digital decoding circuitry is used to activate the directional relays for the servomotors.

the six servos. The counter switch for the elbow servo is shown at the top of figure 2. It is a lever type switch with a small roller which rides on a two-lobe cam fastened to the servo lead screw. As a result, the switch contacts are closed twice during each lead screw revolution. One lead from the switch goes to a common connection joining one side of six of the input-bit positions on the 8-bit interface board. The other lead is connected to one side of relay A and then to the input-bit 2 position on the interface

board. When the two contacts of an input-bit position are connected, the computer reads a binary 1 in that bit position.

Assume that the computer issues the command OUT 3,4. Relay A closes and the forearm is driven in the forward direction. At the same time, since the counter switch circuit is also enabled by relay A, a binary 1 signal from the counter switch reaches the input-bit 2 position twice during each lead screw rotation. In between the switch closures the open switch

		"Forward"		"Reverse"	
		Command		Command	
Axis	Movement	BASIC	Binary Outbit# 76543210	Movement	BASIC
Body	Clockwise	OUT 3,1	00000001	Cntclock	OUT 3,65
Shoulder	Lift	OUT 3,2	00000010	Lower	OUT 3,130
Elbow	Lower	OUT 3,4	00000100	Lift	OUT 3,196
Wrist Pitch	Lift	OUT 3,8	00001000	Lower	OUT 3,72
Wrist Roll	Clockwise	OUT 3,16	00010000	Cntclock	OUT 3,144
Hand	Close	OUT 3,32	00100000	Open	OUT 3,224
Other Commands					
Initiate Homing Mode		OUT 3,128	10000000		
Terminate Homing Mode		OUT 3,64	01000000		
Unassigned		OUT 3,192	11000000		

Table 2. Armega 33 servo commands.

registers as a binary 0. Since the binary 1 occurs in the third bit position, the whole input byte is read as 00000100 (decimal 4), each time the switch closes.

The binary 1 pulses from the elbow servo counter switch occur at the rate of about 20 per second. In order to read these pulses, the computer must detect the change from a binary 1 to a binary 0. To ensure that none of the pulses are missed, the computer must scan the interface board input byte several hundred times per second.

The BASIC program to accomplish this is relatively simple. Suppose that we want the forearm to move forward until the counter switch has produced 51 pulses, and then stop. (This is equivalent to 25½ rotations of the lead screw since there are two pulses per revolution). A BASIC program to accomplish this is shown in listing 1.

Although the program in listing 1 produces a forearm movement of 25½ revolutions, it does not stop the movement precisely. The inertia of the rotating servomotor, reduction gears, and the lead screw itself, causes the servo to *coast* for a fraction of a revolution. To stop the

```
10 OUT 3,4
20 A=INP(3)
30 IF A=0 AND SW=1 THEN C1=C1+1:
   SW = 0: GOTO 60
40 IF A=0 GOTO 20
50 IF A=4 THEN SW=1
60 IF C1=51 THEN 80
70 GOTO 20
80 OUT 3,0
```

Listing 1. A BASIC program for moving the forearm forward until the counter switch has produced 51 pulses. This is equivalent to 25½ lead screw rotations. C1 is the cumulative count of pulses, SW is a program switch which can be set at 1 or 0.

movement crisply and with almost no perceptible coasting, we can momentarily reverse the servo and then go to the OUT 3,0 command. To do this we can substitute and add the lines shown in listing 2.

Line 80, instead of stopping the servo, now reverses it for a length of time determined by the subroutine in line 1000. The program then proceeds to line 100 and issues the OUT 3,0 command to cut off

```
80 OUT 3,196
90 GOSUB 1000
100 OUT 3,0
1000 FOR N=1 TO 3800
1010 NEXT N
1020 RETURN
```

Listing 2. Adding these program lines to listing 1 reverses the servo power briefly when stopping motion. This leads to a much more abrupt stopping motion.

servo power. The count of 3800 shown in line 1000 only represents a fraction of a second but will abruptly stop the forearm movement. I determined the appropriate *braking delays* empirically for each servo.

The counter switch function and programming pattern outlined above is typical of all but one of the servos. The hand does not use a counter switch. Feedback signals from the hand indicate two conditions, fully open or fully closed.

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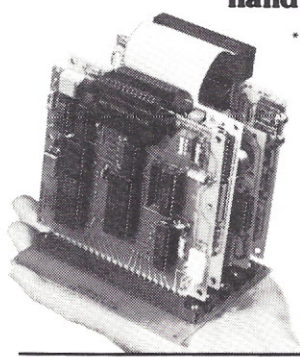


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It is possible, of course, to set the home position through manual control. However, this is tedious and time-consuming and cannot normally be done with the uniformity which can be obtained with computer-controlled homing. In addition, the arm cannot really be said to be under full computer control if it cannot carry out a programmed sequence, index itself to the home position, and then repeat this sequence as many times as desired.

Photo 10 shows the arm in the home position. The base is rotated to the clockwise limit, the bicep is at the full lift limit, the forearm is at the full lower limit, the wrist pitch is in the full lift position, wrist rotation is in the neutral position, and the hand is fully open.

Photo 10 also shows a general view of the arm testing setup. The 8-bit interface board is in the aluminum case to the left of the keyboard. The shelf below the tabletop contains (from left to right) relay and circuit board power supply, servo power supply, ammeters for each power supply, manual control console, and the main circuit board.

The homing control system utilizes some of the hardware features already discussed along with a number of new elements. An element which does double duty is one of the two limit switches which are installed on each arm element to stop movement when the maximum range of movement is reached. These limit switches were previously described as a safety feature to prevent damage as a result of inadvertent control actions.

Referring to figure 2, note that the lowering limit switch is connected to a wire leading from the center switch terminal to the coil of relay C. When the elbow is driven in the lowering direction, the +12 V servo power supply is connected to the

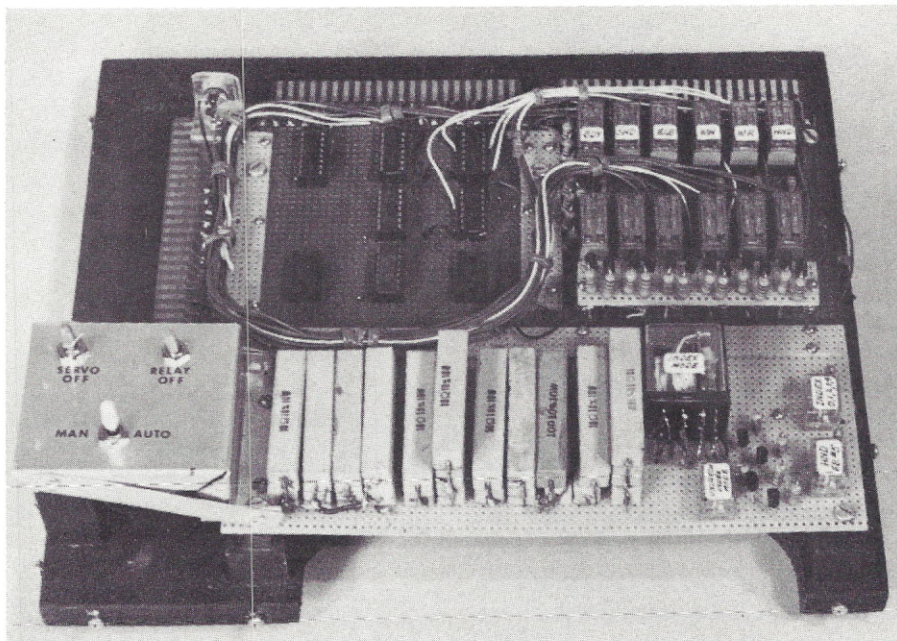


Photo 9. The main circuit board includes servo switching relays and decoding logic. Toggle switches are for servo power supply, relay and integrated circuit power supply, and for switching servo power from computer control to manual control. The manual control console attaches to the main circuit board through a 44-pin edge connector. The arm cable attaches at top left and the input/output cable at top right.

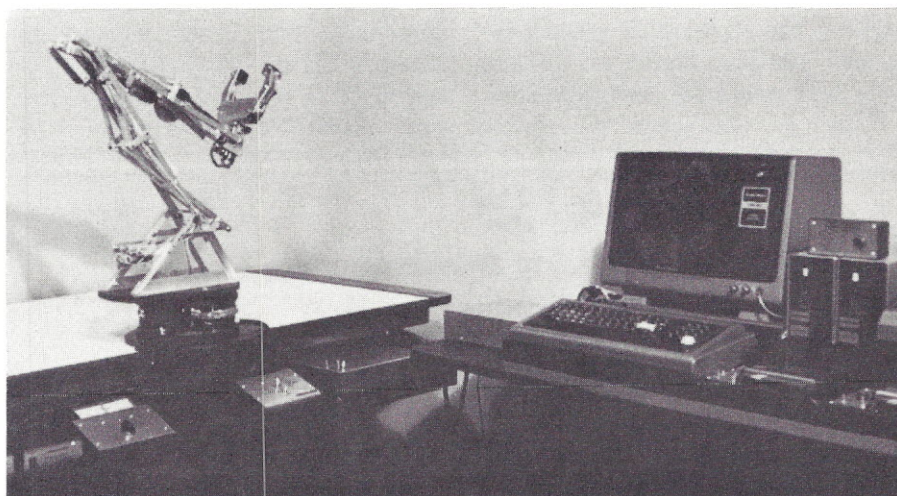


Photo 10. General test setup for Armega 33. The arm is shown in the home position. The shelf below the table edge contains, left to right: relay and integrated circuit power supply, servo power supply, ammeters for power supplies, manual control console and the main circuit board. The control computer, a TRS-80 Model I, is at the right, with the input/output circuit board to the left of the keyboard.

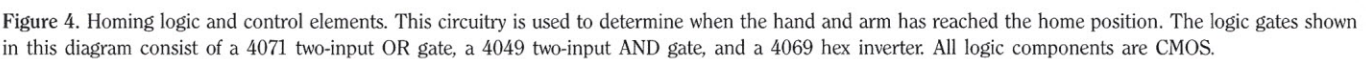
common terminal of this limit switch. When the arm reaches the limit of movement, the limit switch is thrown and cuts the servo current. However, the limit switch is itself a single-pole/double-throw switch which switches the +12 V to the center terminal and thence to relay C. This activates relay C which, in turn, connects the two contacts for input-bit 5 on the interface board and presents a binary 1 at that position. The resulting input byte is 00100000 which is read by the control program as decimal 32.

As a result of this sequence of events, the computer detects a decimal 32 value at the input byte when the forearm reaches its home position. This is an important element in the homing sequence. The arm elements are driven to their home positions one at a time so that input-bit 5 can be used to detect the arrival at the home position for all six arm servos. This is also the method by which feedback from the hand is obtained during normal operation. When the command OUT 3,224 is given to open the hand, the control program

The homing control system involves some additional digital logic and some additional power switching relays. The added logic is required because still another burden is placed on out-bits 6 and 7. In addition to handling the servo reversing chores previously described, out-bit 7 is now used to establish a homing mode, and

Remember that when the servo motion was reversed, out-bits 6 and 7 were always activated in combination with one of the A type relays. In the case of homing, we want the homing mode activated when there is a binary 1 *only* in out-bit 7 location, i.e., 10000000 (decimal 128). The

There are two basic reasons why the arm must be placed in a special mode to complete the homing sequence. First, the limit switches are never activated during normal operation. They are present only to stop inadvertent attempts to drive the elements past their normal limits. The arm elements move at a significant rate of speed (up to 0.7 radians per second) and crashing into




```

500 REM * INDEXING MODULE *
510 CLS : OUT 3,0
520 OUT 3,128
530 GOSUB 10000
540 PRINT @ 274, "INDEXING UNDERWAY"
545 OUT 3,1
550 A=INP(3)
560 IF A>16 THEN 580
570 GOTO 550
580 PRINT @ 338, "BODY IS HOME"
585 OUT 3,2
587 GOSUB 10000
590 A=INP(3)
600 IF A>16 THEN 620
610 GOTO 590
620 PRINT @, 402, "SHOULDER IS HOME"
625 OUT 3,4
627 GOSUB 10000
630 A=INP(3)
640 IF A>16 THEN 660
650 GOTO 630
660 PRINT @ 466, "ELBOW IS HOME"
665 OUT 3,8
667 GOSUB 10000
670 A=INP(3)
680 IF A>16 THEN 700
690 GOTO 670
700 PRINT @ 530, "WRIST PITCH IS HOME"
705 OUT 3,16
707 GOSUB 10000
710 A=INP(3)
720 IF A>16 THEN 740
730 GOTO 710
740 PRINT @ 594, "WRIST ROLL IS HOME"
745 OUT 3,224
747 GOSUB 10000
750 A=INP(3)
760 IF A>16 THEN 780
770 GOTO 750
780 PRINT @ 658, "HAND IS HOME"
785 OUT 3,0
790 OUT 3,64
800 GOSUB 10000
810 OUT 3,0
820 PRINT @ 722, "EVERYBODY HOME NOW, BOSS"
830 GOSUB 12000

-----
10000 REM * DELAY FOR LATCHING RELAYS *
10010 FOR N=1 to 985
10020 NEXT N
10030 RETURN
12000 REM * DELAY FOR READING SCREEN DISPLAY *
12010 FOR N=1 TO 12850
12020 NEXT N
12030 RETURN

```

Listing 3. The BASIC Homing sequence program. This program, which is run at the beginning and end of most control sequences, ensures that the arm is always placed in a known starting position.

a limit switch at full tilt involves at least a minor degree of violence. Conversely, the homing mode deliberately drives each arm element to the point where it is stopped by a limit switch. Accordingly, it is desirable to reduce the normal rate of movement when in the homing mode.

The second special homing requirement is the need to enable the wrist rotation limit switch. This limit switch is normally disabled during arm operation since it may be desirable to rotate the hand as many as six revolutions without interruption. When going to its home position, however, wrist rotation must be accurately stopped at a known position. This is permitted by enabling the limit switch during homing.

The upper portion of figure 4 shows the digital logic elements of the homing system. Relays and electronics are shown in the lower part. The digital logic consists of seven OR gates, four AND gates, and three inverters. This decoding logic detects the occurrence of a binary 1, only at out-bit 7, or only at out-bit 6. (The logic also recognizes the occurrence of 6 and 7 only, but this is not being used at present.) Referring to command list in table 2, we see that binary 1s are constantly recurring in out-bits 6 and 7 during servo reversals. However, they always occur in combination with one or more additional out-bit positions. As long as this remains true, the homing mode will not be triggered by out-bit 7 in combination with a 1 in any other bit. Out-bit 7 in isolation however, (equivalent to decimal 128) produces a binary 1 at the output of the final AND gate. This signal, when amplified through a driver circuit, throws relay D a four-pole, double-throw relay.

The four circuits thus closed perform the following functions:

1. A 10 ohm, 10 W resistor is added in-line to the power supply line from the servo power supply. This slows down the speed of all arm elements during the homing sequence.
2. The wrist rotation limit switch is activated. As a result, wrist rotation is stopped in the neutral position during homing.
3. The homing limit switches of all arm elements are connected to relay C. This is the same relay which provides the hand feedback signals during normal operation, and which produces a binary 1 at in-bit position 5 on the interface board, when it is thrown.

4. Relay D is latched in the thrown position until the homing sequence is complete. Upon completion, the control program places a binary 1 in the out-bit 6 position (equivalent to decimal 64) which throws relay E, unlatches relay D, and thus terminates the homing mode and restores the normal operating mode.

The homing control program for Armega 33 is given in listing 3. Line 520 issues the command `OUT 3,128` which places the arm in the homing mode. The `GOSUB 10000` command in line 530 produces a very short delay, about 0.01 second, to give relay D time to latch. Line 540 places a message on the video display which indicates that the homing sequence is underway. Line 545 starts the base rotation servo in the clockwise direction. Lines 550 through 560 keep scanning the input byte of the interface board until a number greater than 16 appears. When this happens, the computer displays "BODY IS HOME" on the video display.

Line 560 seeks a value greater than 16 to ensure that the value being read at the input byte is a result of the closure of relay C. When the `OUT 3,1` command is given to start the base clockwise, the pulse counting for the base servo which puts a series of binary 1s and 0s in the in-bit position 0 is also activated. Similarly, all of the other counter circuits are activated during homing and generate pulse signals. The highest value from this source will be 16 (from the wrist rotation counter). A value greater than 16 indicates that the homing relay has been thrown and that the element is home.

The program in listing three repeats the above outlined process, in turn, for each body servo: the shoulder (lifting direction), the elbow (lowering direction), wrist pitch (lifting direction), wrist roll (clockwise direction) and hand (fully open). Upon completing the homing for each element, a message is written on the video display so that the entire series can be traced. After the hand reaches the home position, line 785 opens all servo switching relays with an `OUT 3,0` command and line 790 executes an `OUT 3,64` which throws relay E, unlatches relay D and terminates the homing mode. The `GOSUB 12000` in line 830 is a 3 second delay loop which retains the video display long enough to be read.

The end result of all of this activity is to reliably and accurately place the arm in the home position portrayed in photo 10,

starting from any configuration that the arm may have been in when the homing sequence was activated. In all operating control programs for Armega 33, the homing sequence appears both at the beginning and the end of the program. Despite the lengthy explanation, the actual homing procedure typically requires only a few seconds.

Returning to photo 9 (the main circuit board) we can now identify the remaining features. The integrated circuits at the upper left include two quad two-input OR chips, one hex inverter chip and one quad two-input AND chip for the homing logic. This is in addition to the two AND chips previously identified for the reversing logic. The large relay at the lower right is the homing mode relay D. The small relay just below it is the unlatching relay E and the small relay at the extreme lower right is relay C. The remaining small relay was not shown in figure 4 and simply throws in parallel with relay D to route all the homing limit switch leads to relay C.

The 10 W resistors along the lower edge of the board include the homing slow-down resistor of figure 4. The additional large resistors could be described as servo tuning resistors, which have been inserted in the servo power leads to provide a power voltage drop for the small servomotors and a differential voltage for the lifting and lowering power leads to the shoulder, elbow and wrist pitch servos. The shoulder servo, for example, has to lift the weight

of almost the entire upper arm when lifting, even without a useful load, whereas the same weight tends to drive it down in the reverse direction so that it runs noticeably faster. By placing a resistor in the lowering power lead, an almost uniform speed of movement in both directions can be attained even with substantial loads. Jacks at the upper left of the main circuit board are used for connecting the leads from the two power supplies. The three switches at the lower left provide servo power on and off; relay and integrated circuit power on and off; and selecting whether the servo power is connected to the manual control console, the circuit board relays, or off.

Electronics Summary. Although a large amount of actual components are used in the overall control electronics, the actual design is relatively simple and straightforward. Elementary logic circuits are used to determine the arm motions and modes.

Next month concludes the Armega 33 construction details by describing the control computer and the operating programs.

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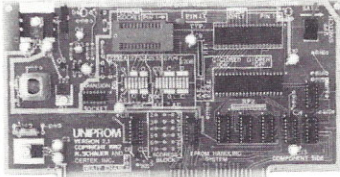
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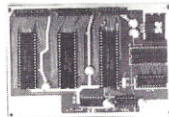


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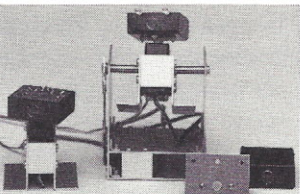
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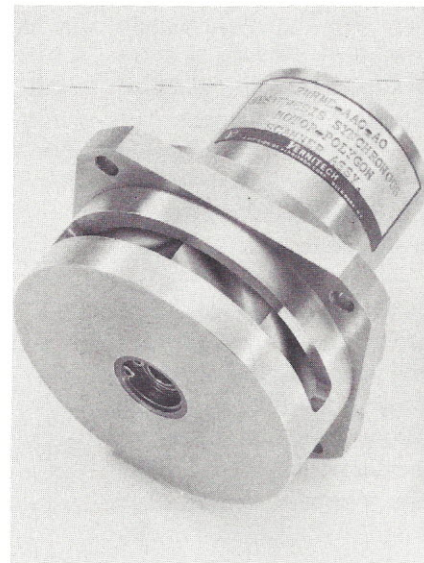
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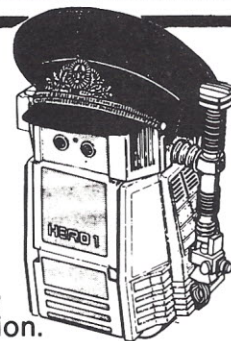
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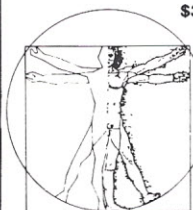
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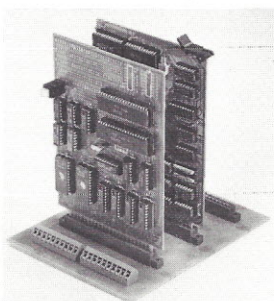
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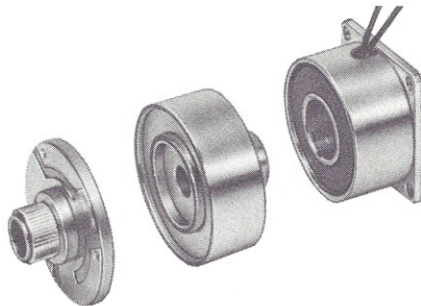
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The chip set, GL-1000 and GL-2000, and the DMC-100 are fully programmed; the user need only command the desired movements and actions from a host terminal or computer. The GL-1000 interface IC is available independently for those users who prefer to

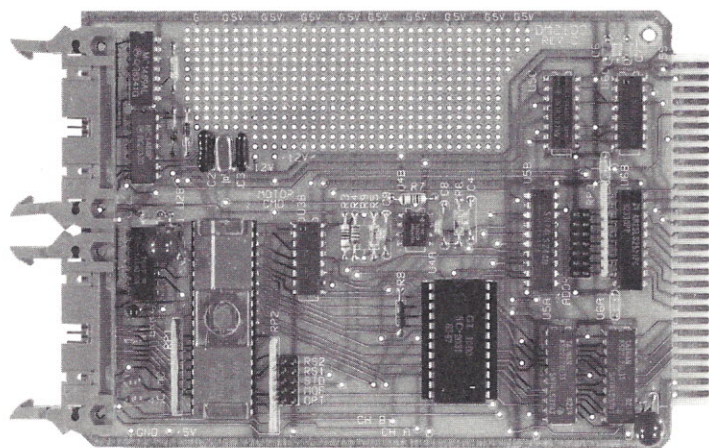
program their own controller. The chip provides position feedback decoding and motor command.

An application note is also available that describes the DMC-100 in detail and illustrates the step-by-step procedure for

utilizing digital servo.

For more information, contact: Dr. J. Tal, GALIL Motion Control, 49 Showers Drive #G442, Mountain View, CA 94049, telephone (415) 948-6551.

Circle 43



New Products

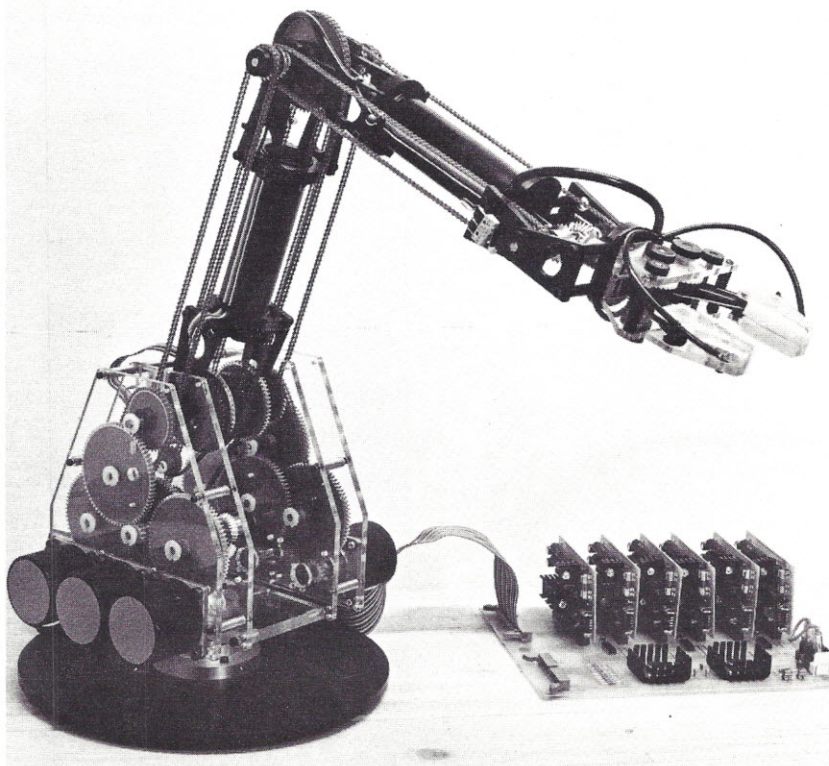
High Tech from Down Under

Flexible Systems, manufacturers of the Tasman Turtle and Turtle Tot, will shortly release a research-oriented manipulator designed by Robotnick P/L of Australia. The arm, recently featured at the Las Vegas Comdex Computer Show, utilizes an open structure allowing user modification.

The arm has five axes of movement, plus gripper action driven by base-mounted bilevel stepper motors, providing high step rates at full power for maximum performance, and trickle currents for holding torques at zero step rates. Pickup payload is 1 kg at its full extension of 750 mm (27.5 in.). Software is available for the Apple, the IBM PC, and CP/M-based machines, as well as a Z80-based controller that can operate as a slave computer or standalone controller/development system.

For more information, contact: Harvard Associates, Inc., 260 Beacon Street, Somerville, MA 02143, telephone (617) 492-0660.

Circle 44



High Force-to-Weight Ratio Gripper

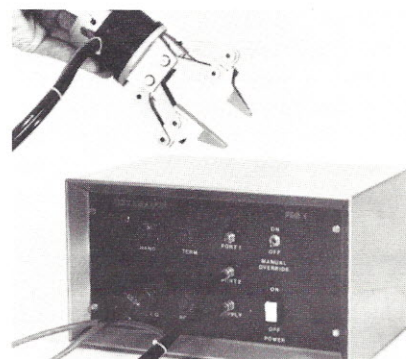
A lightweight, RS-232-compatible, pneumatic servo gripper that interfaces directly with Puma robots is being introduced by Flexamation Robotics Systems of Johnston, Rhode Island.

The Flexamation PSG-1 Pneumatic Servo Gripper, priced from \$4,900, features a maximum gripping force of 100 lbs., but weighs only 2.15 pounds. Providing less than one second positioning time with ± 0.02 inch repeatability, the gripper opens a full 2.75 inches and has optical cross-fire

sensors in the fingertips for workpiece detection. It has pointed tips for bin picking and an adjustable overload sensor in the base, with spring compliance for safety. A complete system consists of a 13.25 by 9 by 7.75 inch controller, the gripper, and related hardware.

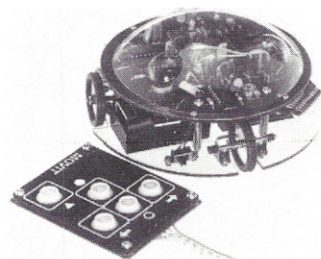
For more information, contact: Flexamation Robotic Systems, David A. Martino, Engineering, 14 Harrington Drive, Johnston, RI 02919, telephone (401) 944-2242.

Circle 45



Memocon Crawler

Stack Model Parts of New Hyde Park, New York has introduced a programmable robot kit with applications to school science projects, robotics courses, or personal enjoyment. The robot includes an on-board programmable CMOS 256 word by 4 bit sequencer which can be programmed through any popular microcomputer having a parallel interface. The attached teach pendant can be used to program the robot to go forward, go right, go left, pause, sound a buzzer, light an LED lamp, or repeat a



program continuously. The three-wheeled, 5 1/2 in. diameter robot known as Model

4Z6-918 Memocon Crawler is offered for \$79.95 in kit form with four pages of easy-to-follow mechanical assembly instructions. All electronic elements are contained in two presoldered and pretested printed circuit boards. Power is supplied by one 9V and two AA batteries (not included).

For more information, contact: Stock Model Parts, Division of Designatronics, Inc., 54 South Denton Avenue, New Hyde Park, NY 11040, telephone (516) 328-3333.

Circle 46

New Products

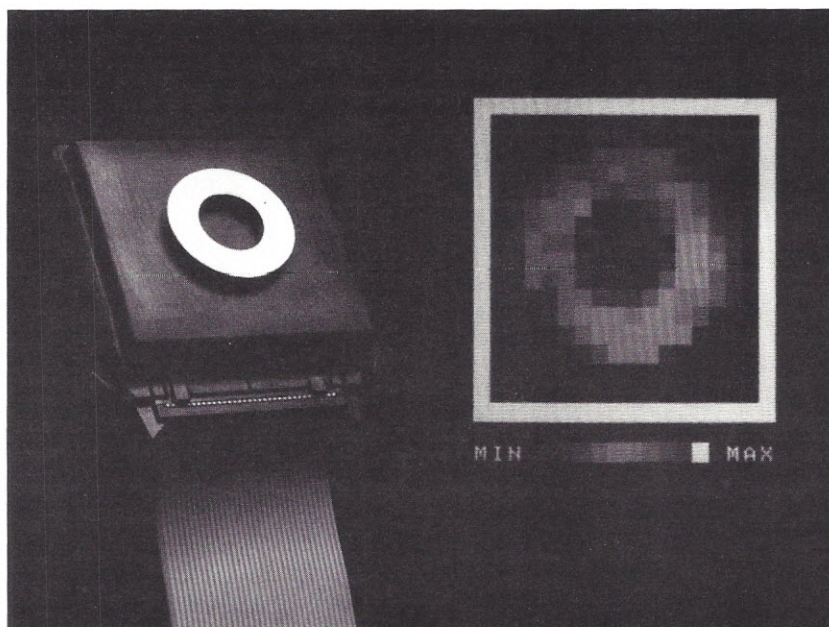
Vision System for Industrial Inspection

Cognex Corporation has announced its newest product, Checkpoint™, a sophisticated vision system for industrial inspection. Checkpoint is a flexible system which the user can easily teach to perform a wide range of inspection and quality control tasks such as: label inspection; print quality inspection; keycap inspection; and printed circuit board inspection, including lead sensing, component placement, and component verification.

The basic Checkpoint system consists of four hardware components (the Checkpoint processor, a camera, monitor and keyboard) and Cognex's proprietary software for image acquisition, analysis, and storage. This basic system can be used in any inspection task that requires checking the presence/absence, shape and positioning of a well-defined item such as a part, a product label or a string of etched or printed characters.

Checkpoint eliminates the subjectivity associated with human visual inspection and performs its inspection tasks with objectivity, accuracy, and consistency of results. It also eliminates the need for sampling. The system can provide 100 percent product inspection.

For more information, contact: Mary E. Doyle, Cognex Corporation, 72 River Park Street, Needham, MA 02194, telephone (617) 449-6030. Circle 47



Tactile Sensor System

Barry Wright Corporation of Watertown, Massachusetts has developed a low profile, compliant touch sensor that provides force, position, and orientation feedback. This touch sensor, the TS 402 Tactile Sensor System, consists of one sensor pad—P/N TS 402-P1 and one interface device—P/N TS 402-D1.

The sensor yields an array of 256 individual data points, with a point-center-to-point-center distance of 0.1 in. An electronic

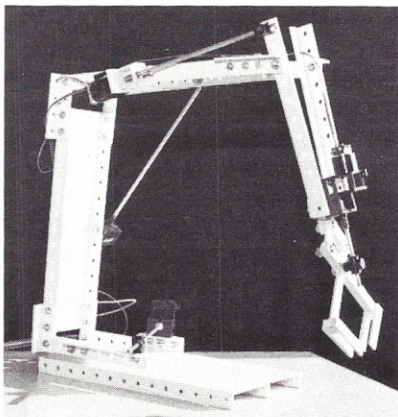
interface is available which operates with a 5V input and 5V output. The output is expressed as an 8-bit digitized signal. An integrated microprocessor/interface device is available as an option.

For possible field testing of the system by qualified Robotics/FMS applications, and for more information, contact: Barry Wright Corporation, 700 Pleasant Street, Watertown, MA 02172, telephone (617) 923-1150. Circle 48

Q-Bots

Eastern Machinery and Manufacturing, Inc. of Salt Lake City, Utah has announced the availability of Q-Bots—kits of robotic components whose basic concept is education. Q-Bots are teaching tools designed to show by instruction and experimentation how electromechanical devices work, prototyping real work applications.

A kit includes eight motor assemblies, two power wheel assemblies, two light sensors, two magnetic sensors, one claw assembly, and the necessary bases, wheels, and parts for building a variety of functional robots. The clear and concise instruction manual explains how to build a mechanical arm and an automated cart that utilizes light sensors



Circle 49

to follow a white line, and how to automate a vacuum cleaner. The cost is \$500.00 per kit.

Q-Bots introduces the home computer user to robotic and electromechanical devices. Any personal computer can interface with Q-Bots over an RS-232 printer port. The computer stores and executes the programs needed to direct or cue the robots.

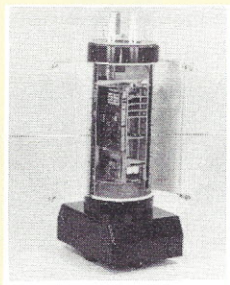
Users are encouraged to experiment and to develop add-ons in both software and hardware for possible inclusion with the kits.

For more information, contact: Carol M. Meyers, president, Communications Network, 6477 Telephone Road, Suite 551, Ventura, CA 93006, telephone (805) 644-0400.

1984 ROBOTICS AGE PRODUCT GUIDE

Robotics Age Product Guide:

A Sourcebook for
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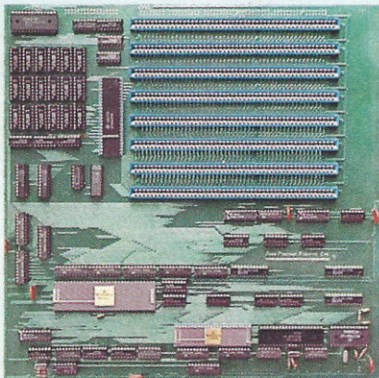
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MARVIN MARK I

The Most Sophisticated Personal/Educational Robot Available

Single Board Computer/Motherboard. Processor - Motorola® M68000 16 brf microprocessor. System Memory - 128K bytes RAM expandable to 512K byte on board, expandable to 8M byte by S-100 board ROM up to 16K bytes. System 102-RS232 serial ports one-parallel port. These are for communication with the outside world, internal communications between servos and computer are taken care of directly.



BRAINS

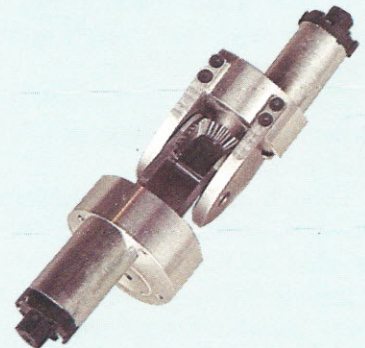
Expansion Bus - 8 slot S-100/EEE-696 expansion bus. Intelligent Servo Controller - Resident on the expansion bus is one S-100 card with 16-full 4 quadrant power MOSFET pulse width modulated servo controllers with axis feedback and auto refresh. This Iowa Precision Robotics Ltd. Model 68-100 computer supports CP/M® 68K and Forth operating systems. It is also used in our industrial Robot Controller where it meets exacting requirements.

BEAUTY

Anthropomorphic design sculptured body skin adds a finishing touch to the fully machined aluminum inner structure.



Two arms, each with:
Axis One: Shoulder is powered thru 135°. The motion you use while bowling. Axis Two: Shoulder is powered thru 105°. The motion you use doing jumping jacks. Axis Three: Upper arm is powered thru 135° of rotation. The motion you use while arm wrestling. Axis Four: Elbow is powered thru 115°. Axis Five: Wrist is powered thru 90°. Axis Six: Gripper opens up to 2½ inches and closes down to zero. All arm servos are powerful enough to enable 'MARVIN' handling a minimum five pounds load in each gripper. (A six pack of your favorite beverage weighs approx. 4½ lbs.)
In addition to the 12 arm axes, 'MARVIN' has: Neck is powered thru 180° rotation. Waist is powered from straight up to 50° forward. This enables him to reach the floor with his grippers.



BRAWN

Drive Wheels: Each drive wheel is an individual servo to enable directional control. His maximum rate of forward speed is 50 inches per second and he has enough power to climb a 10° incline.

- The MARVIN MARK I is ready NOW! We would like to cordially invite you to see MARVIN MARK I at the International Personal Robot Congress and Exposition, April 13th thru the 15th at Albuquerque Convention Center, Albuquerque, New Mexico. This will be a unique opportunity to research the educational robot market in one location. We are positive when you see MARVIN MARK I and compare his advantages to other personal robots you will want to take him home.
- MARVIN MARK I has many outstanding features that set him apart from all other educational robots.
1. 68000 CPU based on board computer/state of the art.
 2. S-100 Expansion Bus-a standard feature.
 3. CP/M compatible.
 4. Two 6 axes Arms - 5 lbs. payload per arm.
 5. Simultaneous use of ALL Axes - allows both arms to work on coordinated tasks.
 6. Variable speed and direction on ALL axes.
 7. Park MARVIN MARK I anywhere and you have a mobile, blackout proof, personal computer with a disk drive and more capabilities than most business computers.
 8. The list goes on and on.

The best news is MARVIN MARK I's price! \$5,995.00! MARVIN MARK I cost less than comparable business computers with the same capabilities and you get the state of the art in educational robots, MARVIN MARK I as a bonus! Order today to avoid delivery delays as orders are piling up and 1984 production is limited. A color brochure is available for more information. "SEE YOU AT THE SHOW".

Iowa Precision Robotics, Ltd.

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Circle 8